On the Beta Diversity of the Afromontane Rainforests of Rwanda.
Patterns in Environment and Vegetation and the Spatial Relationships among them.

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List of Abbreviations

adj.	Adjusted
CCA	Canonical Correspondence Analysis
CI	Confidence Interval
dbMEM	Distance-based Morans Eigenvector Maps
DEM	Digital Elevation Model
EC	Electrical Conductivity
FCM	Fuzzy C-Means
FCM-NC	Fuzzy C-Means with Noise Clustering
SOM	Soil Organic Matter
LCBD	Local Contribution to Beta Diversity
PCO	Principal Coordinate
TWA	Topographical Wetness Index
tb-RDA	Transformation Based Redundancy Analysis
db-RDA	Distance Based Redundancy Analysis
UPGMA	Unweighted Arithmetic Average Clustering Unweighted Pair-Group Method using Arithmetic Averages
VIF	Variance Inflation Factors

1 Introduction

In the following paragraph, an introduction of the history of botanical research in Rwanda with an emphasis on the current survey area will be given along with an overview of the resulting literature. Beyond some comments, the reasoning for the survey at hand will briefly be outlined. The end of this section contains a sparse description of the study site. First, a brief introduction to Rwanda will be given.

1.1 Introduction to Rwanda

With a southern latitude between 1° 04' and 2° 51' and an eastern longitude between 28° 53' and 30° 53', Rwanda covers an area of 26,338 km^2 in central Africa. The country is characterised by an equatorial climate moderated by its elevation. According to the World Bank, the population is currently 12.60 million. The resulting population density is one of the country's greatest challenges. In terms of natural resource conservation, the situation is further exacerbated by a population of which 70% is dependent on (subsistence) agriculture. The economy of the country is currently in a transformation process towards a modern economy (THE WORLD BANK GROUP, 2021). Public investments resulted in a GDP growth of 10% in 2019. Challenges lie in the increased public debt, high energy costs, an insufficient stake of the private sector in the economy and investment, low domestic skills and inclusive growth. However, poverty has been reduced to 55% in 2017 (THE WORLD BANK GROUP, 2021, retrieved March 2021).

The geography of the country is in the eastern part characterised by savannas that transition into extensive wetlands towards the border with Tanzania. The elevation a.s.l. ranges between 1300 m and 1600 m. Towards the west, the altitude increases and reaches 1500 m to 2000 m on the central plateau. The western part of the country is dominated by the hills and mountains of the Albertine Rift, the western part of the East African Rift Valley. The mountain range is part of the Congo-Nile Divide, and most of it exceeds 2000 m a.s.l. The Virunga Volcanoes in the northern part towards the border with Uganda and the D.R.C. include the highest mountains in the country at 4507 m a.s.l. The western slopes of the range drop steeply to the shores of Lake Kivu. Its distinctive topography gave the country the name "Land of a Thousand Hills".

1.2 Historical Overview of the Exploration, Exploitation, Development, Condition and Prospects of Rwanda's montane Rain Forests

Rwanda, then a kingdom, was entered by Europeans only late in the 19th century (GLOBALSECURITY.ORG, 2016). A few British explorers passed by (Sir Richard Burton in 1855 and John Hanning Speke in 1855 and 1861) but never entered the realm (IBID.). Maybe because of what VON GÖTZEN (1895) later called "Sagenbildung über Ruanda" (Sagas about Rwanda). Maybe they knew that not even the Arabs could conquer the Rwandan people and then refrained from further ventures into the inaccessible and hazardous area (VON GÖTZEN, 1895). Then again, not everything may have been a myth. According to KING (2006) Henry Stanley was "greeted by a storm of arrows" in 1874. Thus, it was only after 1885 that interest in the region grew when it had been decided to put Rwanda under German rule. Up until 1892, Rwanda had thus been almost completely secluded. The first European to be welcomed there was Oskar Baumann in 1892 (Baumann, 1894). He laid some of the cartographical groundwork that future expeditions relied on (ibid.). Finally, in 1894 the first large scale expedition led by Count von Götzen passed through Rwanda. Adolf Engler was the first to describe some of the plants found by von Götzens expedition (Engler in von Götzen, 1895). The survey was mostly confined to the collection of specimens and the description of the vegetation of the Kirunga (Virunga) volcanoes. Most of the surveys during the following decades were focused on the compilation and description of species new to science. Some of the most important researchers will be listed here. For a more comprehensive listing, the reader may be referred to Walraet (1966) who provides an overview of the surveys conducted in Rwanda between 1894 and 1965.

Right at the beginning of the colonial era, Richard Kandt the German Resident in Rwanda (1907-1914), gave a rough impression of the vegetation and built a botanical collection (Kandt, 1914; Mildbraed, 1914). An expedition through Central Africa from 1907 to 1908, led by the Duke of Mecklenburg, brought about further insights into the Rwandan flora. While according to von Götzen (1895) the Kirunga (now Virunga) bore dense forest, von Mecklenburg (1909) reported on his way into innermost Africa, that the "forest question" is a burning one. Besides Urundi (Burundi), Rwanda was probably the most densely populated area in Central Africa (ibid., p. 96). The Duke of Mecklenburg then found that the forest cover already had given way to the then 1.5 mio inhabitants (ibid., p. 96). Here, the origin may be found about 2500 years ago with the arrival of modern man (Chao et al., 2012). Further migration into the area occurred 1700 years ago from the west and north (ibid.). Although the natural forest is supposed to have exended about 19.3 km east of its current position in 1907 (ibid.), within its borders, Rwanda only had two larger forests left, the Rugege (today Nyungwe) and the Bugoie (today Gishwati). The large centre of the country was already completely devoid of forest (von Mecklenburg (1909, p. 96). Another observation by the Duke implied an active landscape as he described an alternation between forest and clearings, which seems to be of none anthropogenic origin (ibid.).

As part of von Mecklenburg's expedition, Johannis Mildbraed collected not only plants from the volcano region but also from the Rugege mounatin range, which is now known as the Nyungwe National Park. In 1911, before Mildbread published his results, Hans Meyer (1913; see Engler, 1919)collected plants from the volcano range, an island in lake Kivu, as well as from the Muwissi and Gaharo mountain ranges, which constitute the eastern part of the Nyungwe forest. According to Mildbraed (1914), Hans Meyer described the vast forested area as uninhabited. When Mildbread himself ventured towards the southern end of lake Kivu, he noticed open scrub formations of *P. aquilinum*. He noted: „[…] [D]ie Berge östlich der großen Mecklenburg-Bucht des Kivu-Sees tragen offene Formationen […] dessen Stelle früher sicher […] von jetzt vernichtetem Wald eingenommen wurde" (Mildbread, 1914, p. 620). Towards the Bugoie forest (now Gishwati), he noticed the advanced agricultural region and stated that a forest similar to the Rugege forest must have expanded deeper here in the past. Concerned about the devastation of the forests, Mildbread noticed only some canopy emergents were left by the slash-and-burn agriculture and that the soil was not arable enough to bear peas more than once while the forest would never recover (ibid., p. 621). Furthermore, he stated that only a small part of the burnt area would be used at all. The emergent species left around Bugoie were *Symphonia globulifera* and *Pseudocedrela* cf. *excelsa* (*Entandrophragma excelsum*) (ibid.). Among the species listed, he noticed *Ochna holstii* to be among the tallest[1] and to occur on the eastern side of the forest.

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[1] Then under the synonym *O. procera*. The height of which (40-50 m) Mildbread may have exaggerated.

Symphonia globulifera, a similarly tall species, could be found in the lower parts at the margin in the eastern and western parts of Nyungwe forest, as well as in the cleared parts of Bugoie forest. He also noted that *Podocarpus latifolius* only occurred west of the watershed, where he noticed a general change in the vegetation. An illustrative example was the increase in abundance of *Carapa grandiflora*, as well as the occurrence of *Parinari excelesa*, while *M. kilimandscharica* remains of importance. He noted that local contingencies could be the cause of the change and pointed out that one cannot be sure whether a real border exists (IBID., p. 626). At the time of MILDBREAD'S observations, Gishwati Forest was still connected to the forest of the Virunga Volcanoes (IBID., p. 632).

The Virunga Volcanoes were visited in 1930 by BURTT (1934). His extensive collection activities comprised parts of the forests that are no longer in existence on the volcanoes. Which leaves Nyungwe, Gishwati and Mukura as the only places in Rwanda where the described species can be found today. In 1933, Nyungwe forest has been declared a forêst classee by the Belgian colonial administration (SAYER, HARCOURT, & COLLINS, 1992).

In his "Statistiques de nos connaissances sur les Spermatophytes du Congo Belge et du Ruanda-Urundi" ROBYNS stated in 1946 that the botanical exploration is well advanced and that a discovery of many new groups is not to be expected any longer. Considering that he further stated that in 1940 the territory of then Ruanda-Urundi had been comprised for the first time in the census, the former statement might have been a bit hasty. His report is limited to information on the occurrence of gymnosperms, angiosperms, di- and monocotyledones as well as families and further taxonomic units. The same author (ROBYNS, 1948) gave a biogeographic outline of the Parc National Albert in 1948.

As late as 1953, MULLENDERS described the remains of already severely impoverished forest stands from the Goma-Kisenyi area. These sclerophyllous forests, which were adjacent to today's Gishwati forest, are by now completely lost. In 1959, BAMPS started contributing to the knowledge and systematics of the Rwandan plant species (LACHENAUD & FABRI, 2020). He later contributed to the Flore d'Afrique Centrale and to the Flore du Rwanda (IBID.).

GILBERT advanced the "Flore du Congo belge et du Ruanda-Urundi" (in ROBYNS, 1948 -) from 1951 (according to LIBEN, 1984) and later added to the knowledge about "La flore du Congo belge et du Ruanda-Urundi" GILBERT (1958). LEBRUN (1956) (as cited in WALRAET, 1966) was the first to describe "La végétation et les territoires botaniques du Ruanda-Urundi". In 1954, they had jointly published "Une Classification Ècologique des Forêts du Congo" (LEBRUN & GILBERT, 1954). The publication was the first to describe plant communities in connection to ecological conditions on site, which was and still is applicable to parts of Rwanda as well. GEORGES TROUPIN, who since the 1940s' also advanced the knowledge of the Rwandan flora, published the "Flore du Rwanda" in (1978). The four volumes not only represent the first usable identification key but also provide information on the ecology of the particular species. LEFÈVRE (as cited in MOLLARET, 1961) gave a short description of the microflora and microfauna of the lakes on Mt Virunga.

At the nothern edge of the forest, a project commenced in 1967 to establish buffer zones using pine species around the forest edges (PLUMPTRE ET AL., 2002). In 1972, SPINAGE provided an account of the ecology and problems of the Volcano National Park. He briefly outlined the altitudinal vegetation zonation and offered evidence of plant communities that are no longer in existence today.

In his doctoral thesis BOUXIN (1973) undertakes an indirect ordination of the Rwandan vegetation for the first time (unpublished; as cited in BOUXIN, 1977). In 1976, BOUXIN published a first ordination and classification of the upland Rugege forest. Although the study area was restricted to a small part of forest south of the Kamiranzovu peat bog, the results showed ecologically sound results and, thus, the merit of numerical methods. In 1977 Bouxin elaborated on the previous survey, but restricted the results to the tree layer. A quick overview of the plants from Nyungwe forest used in traditional medicine was given by Runyinya in 1978.

Moreover in 1978, Sorg gave a first account on the status and endangerment of the forest reserve. Between 1958 and 1974, 750 ha/a were lost due to agricultural encroachment, harvesting of timber, mining and other activities (ibid.). According to his account, Nyungwe might have vanished within 94 to 134 years (ibid.). His calculation is bolstered by the fact that the threats to the forest have not declined since 1974 (ibid.). He was the first to clearly state the functions and benefits arising from the forest; Sorg (1978) expounded that the hydrological equilibrium in the run-off amplitude, soil protection and the species reservoir to be the most prominent services provided. He was already aware of the need for long term studies, especially on hydroclimatic topics (ibid.). Another important suggestion was for the development of tourism based on light infrastructure while including regional economic cycles. The main threats were identified as logging along roads, mining and with that poaching, as well as pressure due to agricultural development. Since the existence of the people living around the forest was at stake, he advised on regulations and mechanisms beyond mere prohibitions. He suggested the establishment of a National Park provided that the reality of people's situation is accounted for. One of the options to do so would be the reforestation of the fringe zone using exotic and indigenous species. Another option provided by Sorg was the draining of bogs (ibid.). He further mentioned several species that were impacted by forest degradation, e.g., *Podocarpus* sp. and *Entandrophragma* sp. Although his comprehensive review of the situation was not directly concerned with vegetation analysis, the information given directly relates to the ecological interrelations and ultimately to the conservation of the forest.

A cursory overview of the vegetation around and above the swamps in Nyungwe forest was given by Hamilton (1982). Schmitz revised the vegetation units so far described from Zaire, Rwanda and Burundi in 1988. Like his predecessors, he provided information concerning the respective ecological background, did so merely from a descriptive basis. By 1984, the Ministry of Agriculture developed a management plan for Nyungwe forest to divide it into three different zones (Plumptre et al., 2002). The plan foresaw the utilisation of the fringes for timber harvesting, with 40% of the forest to be used minimally as a natural reserve and 50% of the area to be sustainably managed for resource extraction (ibid.). In the same year, the New York Zoological Society (now WCS) set up work in Rwanda (ibid.).

MacKinnon & MacKinnon (1986) reviewed the system of the protected areas in the Afrotropical realm. The authors based their work on White (1983), utilising his phytocoria. For Rwanda, they specified that the transition zone between lowland phytochoria and the Afromontane rain forest has been destroyed almost everywhere. They stated that the Afromontane forest is quite similar to certain types of Guineo-Congolian lowland forest with the exception of tree ferns and conifers. While the western part of the country is the frontier between the Afromontane realm and low-land phytochoria, the whole of the eastern part of the country is included in the Lake Victoria Regional Mosaic. Furthermore, they provided a rough synopsis of the altitudinal zonation of the forests.

In addition to the scientific exploration of the country, the establishment of a tourism programme started in 1987 with the support of USAID (Plumptre et al. 2002). Within the same effort, education programmes for local communities and the training of Rwandan biologists were launched as well as the establishment of a trail system (IBID.). Often cited, DOWSETT-LEMAIRE (1990) gave a rather crude sketch of the vegetation accompanied by some loose presumptions on some ecological relations.

In "The Conservation Atlas of Tropical Forests" for Africa, SAYER ET AL. (1992) contributed a comprehensive overview of the environmental history and state of the forests. While in 1907 (ZU MECKLENBURG, 1909) 1.5 million people inhabited the country, there were 7.3 million in the mid 1990s' (SAYER ET AL. 1992). According to the conservation atlas mentioned above, during the period of 1981 to 1985, 28 km² of forest were lost annually. Thus, by the end of the 1980s, only 1010 km² of closed broad-leaved forest were left (FAO, 1988) as cited in SAYER ET AL. 1992). It is suggested that one third to half of Burundi and Rwanda were originally forested with the major part occurring at the western highlands (WEBER & VEDDER, 1984; RUNYINYA, 1986 as cited in SAYER ET AL., 1992). HARCOURT (1986) and WEBER (1987) (as cited in SAYER ET AL. 1992) assumed that only 6.2% of Rwanda's montane forests still remain. They presented the same ecological services provided by the forests as SORG (1978). Although the transformation of the forests began 2000 years ago, it was only in the second half of the twentieth century that destruction became substantial. WEBER & VEDDER (1984) calculated that the forest edge was pushed back by almost one kilometer per year in the 1920s (as cited in SAYER ET AL. 1992), while the Nyungwe Forest Reserve shrunk 170 km² during that time (HARROY, 1981 as cited in SAYER ET AL. 1992). According to VEDDEr (1985) Gishwati Forest lost 100 km² between 1980 and 1986 and was, thereby, cut in half (as cited in SAYER ET AL., 1992). As described by PLUMPTRE ET AL. (2001), this was the result of a programme initiated by the World Bank to convert the land into pasture and pine plantations. Thus, of the 280 km² of Gishwati existent in the mid-1970s 100 km² were lost due to the above-mentioned events, while another 30 km² were used as a military area, and the 50 km² of natural forest left saw a number of military operations in the post-1994 era, which lasted until 1998 (see also PLUMPTRE ET AL. 2001). While the SAYER ET AL. (1992) gave more detail on the status of the Rwandan forests and the anthropogenic impacts on them, only some information is given on species occurrences and distributions in the different forest forms. FISCHER & HINKEL published an introduction to the Rwandan Nature in 1992. They provided extensive details on the different vegetation formations and fauna occurring in Rwanda. The distribution of different species was given alongside information on basic ecological requirements (IBID.).

HABIYAREMYE (1993) used multivariate methods to establish plant communities and to give some information on their ecological background. His work was the first and, so far, the only one to relate environmental variables and vegetation data. He also included some plant traits which today are incorporated in the functional diversity framework.

In 1993, FISCHER & HINKEL visited the forest remnant called Cyamudongo, situated west of Nyungwe Forest. Until then, the small but species-rich forest had been neglected by science. One year later, the same authors described the flora and fauna of Gishwati Forest, which seemingly had fallen into oblivion after 1907 (FISCHER & HINKEL, 1994). SUN ET AL. (1996) published a report on tree phenology of 49 species, thus adding to the knowledge base necessary to establish and evaluate long term monitoring data.

HABIYAREMYE undertook another attempt to use numerical methods on the vegetation of Rwanda in 1997. Using indirect ordination and an unknown clustering algorithm implemented into the ANAPHYTO software, HABIYAREMYE (ibid.) managed to describe various plant communities in detail. He gave some important insights into the interrelations between vegetation and environmental factors. His focus was predominantly on soil parameters, whereby he was one of the first to elaborate on the interactions between soil variables as well as soil and elevation. Unfortunately, a quantification of the respective impacts could not be given using indirect ordination. This work nevertheless remains one of the few ecological surveys concerned with the relations between vegetation and environmental conditions.

In the year 2000, GILAROWSKI published an article from a forestry point of view. He first provided a brief outline of the settlement history stating that deforestation began early with the smelting of iron ore, sedentary agriculture and, with that, slash-and-burn practices. According to his account, the Virunga Forests and Gishwati became separated only in the mid-20th century. Additionally, to give information on the recent history and conservation activities, he offered concise information on the native species most valued by the local population. Here, Entandrophragma excelsum, Parinari excelsa and Symphonia globulifera seem to be the most pertinent. Among a number of recommendations to balance nature conservation and human development, he promoted agroforestry, the sharing of tourism benefits with the local communities, and rather alarmingly, the draining of swamps and valleys.

Another report on the flora and vegetation of Nyungwe Forest was drafted by EWANGO (2001). He extended a useful overview on the distribution and number of climax and secondary tree and shrub species. Next to this valuable information he only loosely related species diversity to the diverse climatic and environmental conditions.

PLUMPTRE ET AL. (2001) reported on the developments in Rwanda's forests post-1994. Besides giving reasons why Nyungwe was impacted relatively little in comparison to the other forests, they also stated that more damage was done after the war than during. In addition, especially Gishwati and Mukura forests, had already been majorly affected before the civil war and are considered all but lost (IBID.) Until this research, Mukura had never been surveyed with any effort.

Primarily concerned with birds, KANYAMIBWA (2001) provided an extensive synopsis on the Rwandan nature and climatic conditions. Referring to WHITE (1983), the author mentioned the convergence of at least three phytochoria in the region. He further reported on the differenct pedology, precipitation, vegetation, water-flow and biodiversity between the respective sites of the water shed running through Nyungwe and the contigous Kibira Forest in Burundi. Likewise, an introduction was given on the distribution of the most dominant among the over 250 tree species suspected to be present in Nyungwe Forest. He drew a rough classification of the trees dominant at lower altitudes, in mature forests, in secondary areas, along roads and on summits as well as on rocky soils. He raised the point that the decline in forest area from 1958 (114000 ha) to 1979 (97100 ha) was largely at the expense of the forest below 1700 m a.s.l. (KANYAMIBWA, 2001). He briefly mentioned Cyamudongo Forest, quoting its size at 300 ha. According to the author, the forests, although being highly diverse, present only a minor share of endemic species.

Another account on the contemporary history of conservation was given by PLUMPTRE ET AL. (2002); besides that, the authors surveyed mammals, birds and plants of Nyungwe Forest. They collected 242 species of vascular plants among which seven were new records for Nyungwe Forest. Although they gave detailed information on the distribution of the species collected and detailed the clear differences between the eastern and western parts of the forest, they only related environmental conditions to the vegetation patterns found in an indirect way using classification and indirect ordination methods. Here, they stated that the higher species richness and diversity in the western part might be attributable to the lower average elevations of this area. In conclusion, they suggested placing a higher conservation priority on the western part of Nyungwe Forest. Essential advice offered by the authors is to conduct surveys of forest development after fire since these are becoming more frequent.

In a very detailed and elaborate approach, NDAYAMBAJE (2002) identified the plant species preferably and frequently utilised by humans. He categorised the species by application into timber, poles and medicinal. Oriented by SORG (1978), he gave a short list of the occurrences of tree species and general vegetation structure by altitude and also mentioned soil condtions as being of importance NDAYAMBAJE (2002). Citing GAPUSI & MUGUNGA (1997), he listed a number of rare and endangered species as well, which are partly among those he identified as important to the local population NDAYAMBAJE (2002). In closing, he developed a site-specific system based on stem densities per ha by which species could be used sustainably. The major problem according to the author is the uneven distribution of densities of the respective species. The considerable differences in size classes and, thus, natural regrowth are attributed to the heterogeneity in altitudes, soils and different degrees of disturbances. If extraction from the forest is not managed sustainably, he regarded 50% of the favoured species as vulnerable, especially due to the multiple uses of some; a few examples include *Entandrophragma excelsum*, *Newtonia buchananii*, *Syzygium parvifolium* and even *Macaranga kilimandscharica* if exploited freely. NDAYAMBAJE (2002) further promoted this idea, also stipulating the necessity of local community participation, agroforestry projects, tree nurseries for indigenous species and the monitoring of the natural regeneration of pertinent species. He specified the need for more research on the dynamics, constraints in life stages, growth rates, habitat requirements and spatial distribution of the tree species at hand. In order to gain information on forest restoration, he advised one to study highly disturbed sites.

A study of the regeneration of native species in the buffer zone around Nyungwe was undertaken by GAPUSI in 2007. It is well known that certain species alter soil conditions and that their leave litter can prevent regeneration of other species. GAPUSI (2007) ascertained the most common tree species to regenerate in the buffer zones in respect to the exotic species planted and that *Acacia* spp. and *Cupressus* spp. seem to have the least impact on natural species. In his opinion *Pinus* spp. have an adverse effect on seedling density. After detailing the conflicts between local populations and conservation, he identified the threats for the forest. He noticed the preference for *Euclyptus* spp. by the people despite the negative ecological impacts.

The biodiversity of the Albertine Rift was described in detail by *Plumptre et al.* in 2007. While an estimated 5793 species of ferns and higher taxa ought to be occurring within the rift, 1105 species are estimated for Nyungwe Forest. The authors stated that around 137 Albertine Rift endemics occur within the forest and that the high rank of the forest among all the forests of the rift is bolstered as well by the high number of globally threatened species present. They point out that, due to the population pressure of 500 - 600 people per km^2 around the forest, species might get lost even before they got discovered.

FISCHER & KILLMAN published an illustrated field fuide to the plants of Nyungwe National Park in 2008. Here, they also provided some information about habitat and distribution of the respective species.

The effect of road edges on the structure of canopies and epiphyte biodiversity was investigated by NYANDWI in 2008. He found distinct negative effects on the abundance of the species surveyed. Beyond giving evidence on the direct impact of roads on the vegetation, he exemplified some indirect effects as well, including the alteration of micro-climatic conditions in the surrounding habitat.

Plumptre et al. (2012) and Seimon (2012) published climatological prospects for Rwanda estimating the changes to occur during the 21st century. In essence, a redistribution of rainfall maxima was reported to be expected, coupled with an increase in the amount and intensity. The rainfall patterns were described as likely to have an impact on regional ecology and phenology. In addition, an expected increase in temperature of about 3.6 °C was detailed as well. Plumptre et al. (2012) estimated an upward shift of plant species of about 600 to 700 m already considering the 5 to 6 °C / km decrease with altitude. Seimon (2012) specified that a rapid increase in temperature had already been recorded and that systematic monitoring on altitudinal gradients should be able to identify early indications of range shifts of some species. He attested to an elevated risk of fires during the dry season and put the chance of a split of the main rain season into the context. Another alarming development outlined was the change of the forest's function in respect to carbon sequestration from sink to source. The aforementioned increase in precipitation intensity may lead to an elevated risk of landslides and mass movements as well as flash floods. Not only the native flora is threatened by a changing climate, but crops may also be negatively impacted in yield and general growability. Chao et al. (2012) elaborated on the impact of changing precipitation regimes. Likewisee they discussed anthropogenic impacts in more detail, e.g., the result of exotic species on buffer zone soils or the facilitated spread of Pteridium aquilinum. The ecosystem services provided by the forests were detailed as well.

Bizuru, Niyigaba, & Mujawamariya (2014) studied open graslands and ecotones between graslands and closed canopy forest within Nyungwe Forest. They identified eight plant communities comprising 198 species in total. They reported some overlap with montane vegetation from other regions and provided an overview of the phytogeographic distribution as well as the spectrum of life forms of the species found. Among them were 65 species which are restricted to the Afromontane realm. Apart from classifying the vegetation found, they only loosely interpreted the relations between environmental factors and species composition based on indirect ordination. The main impact factors were given as "ancient disturbance after-effects", including edaphic conditions, altitude and general variety within a habitat. As a result, these aspects shed some light on the conservation value of open sites which otherwise are mostly neglected.

Recent studies have been more specialised. Many of them are concerned with soil chemical properties and possible changes stemming from global warming. Nsabimana et al. (2008) were concerned with carbon sequestration in buffer zone soils, pointing out the negative impact of exotic species on nitrogen mineralisation. Cizungu et al. (2014) studied leaf litter decomposition on eucalyptus plantations and concluded that nutrient depletion is highly likely in the long term. The paper of Dusenge et al. (2015) is focused on the photosynthetic capacity of montane species in respect to climate change, i.e., temperature increase. Among the species surveyed, *Entandrophragma excelsum*, *Carapa grandiflora* and *Syzygium parvifolium* exhibited a decrease in photosynthetic capacity under warmer conditions. Vårhammer et al. (2015) were in direct alignment and additionally pointed to the negative impact of elevated temperatures on seedling growth, recruitment, migration and survival rates of tropical montane climax species. An effect on co-occurring biota seems likely as well since they may not be able to persist in non-climax vegetation (cf. Poulsen, Clark, & Bolker, 2011). Even in the event of increasing CO2 levels, the authors characterised the competitive balance being disrupted (Vårhammer et al. 2015). Thus, warm adapted species or pioneer species may outcompete native and climax species. Van der Heyden (2016) agrued that plants adapted to higher altitudes feature a closed nitrogen cycle and show comparatively lower photosynthesis rates. In the event of increasing temperatures, these species are likely to be outcompeted by species from lower altitudinal ranges. TAVEIRNE (2016) offered the first study on functional traits along an elevational gradient in Nyungwe Forest. Along this gradient, he suspected a decreasing availability of niches and observed a change in functional traits pointing to the adoption of a conservative resource strategy under high altitude conditions. The author deemsd the functional diversity approach useful for ecological studies but saw the real merit in combining it with classical taxonomic diversity (TAVEIRNE 2016).

Based on remote sensing, KAYIRANGA ET AL. (2016) found that within the Nyungwe-Kibira Landscape, an average of 4.97 km^2 of forest were lost per year. Evaluating the years from 1986 to 2015, the authors showed that 9.37% or 158.08 km^2 of dense forest cover were transformed into open formations within the borders of the park. Outside the park, 377.60 km^2 of forest were lost. The authors showed that while degradation and fragmentation within the forest were minor, regeneration of only 35.43 km^2 during the same period still remained below the degradation level. Besides the degradation of forested areas, outside of being a concern in itself, the pressure on the protected areas may increase with the disappearance of resources outside the park boundaries.

Although between 1986 and 1994 the degradation intensity in Nyungwe was ten times higher than between 1994 and 2010, it remained high according to RUTEBUKA ET AL. (2018). The same authors affirmed a daily net primary production and carbon sequestration capacity that decreased by 37.1% (IBID.). They claimed that conservation is only effective within accessible areas. NYIRAMBANGUTSE ET AL. (2017) differentiated between late and early successional stages and came to the conclusion that late stages have an average 35% higher carbon stock. They stated the need for local information on species composition to more accurately estimate carbon stocks since the differences in species composition and thus stem density, tree height and diameter directly influence the difference of carbon stocks between primary and secondary forests. According to the authors, surveys on distrubance regimes and succesional stages are in demand. They further stated detailed carbon stocks are likely to be larger in Africa than in South America.

INGABIRE, ISANGE, & MUSABWAMANA, 2019 evaluated the distribution and state of *Prunus africana* in Nyungwe National Park as well as in the newly established Gishwati-Mukura National Park. Despite a concentration of abundance in the northern part of Nyungwe and a lower density in Gishwati and Mukura, the authors still deemed the species as threatened. The reasons are not limited to human impact but extend to an unstable population and a genetic degradation of germplasm due to inbreeding (African Forest Forum, 2011 as cited in INGABIRE et al. 2019).

Pteridium aquilinum is a species native to Rwanda and common in Nyungwe National Park. Due to an increased occurrence of fires, especially during the El-Nino years, about 12% of Nyungwe's area has been lost to fires (SENYANZOBE, MULEI, BIZURU, & NSENGIMUREMYI, 2020). SENYANZOBE ET AL. (2020) surveyed sites impacted by fire and subsequently colonised by *P. aquilinum*. They have established that competitive exclusion reduces species' richness and soil seed banks can be affected after colonisation. The leaf litter seems to be a hinderance for the establishment of phanerophytes as well.

During the 2000s, a significant amount of research focused on the economic status of the population and their relation to the forest as well as people's attitudes towards nature conservation was published (PLUMPTRE ET AL., 2004; MASOZERA, 2002; RUTEBUKA, NSABIMANA & GROSS-CAMP, 2012; LEONE, 2015; UMUZIRANGANE & MUHIRWA, 2017).

Most of the studies focussing on the interaction between man and forest largely restate Sorgs (1978) findings and elaborate on them, while little new information comes to light. Reasons for ongoing illegal use and options to overcome the conflict between development and conservation have been sought and identified. Despite the useful approaches and suggestions, an increasingly growing authorship of Rwandan professionals and students is noticeable. All reports and publications mention illegal tree cutting, honey collection, mining and poaching as the main threats to Rwanda's natural forest. Similarly in unison, a demand for community participation, human capacity building, equally distributed law enforcement as well as education are factors being demanded as a means to ensure intact forests. Leone (2015) offered an important, but largely neglected, landscape approach to comprise all stakeholders and facilitate nature conservation by implementing various measures to increase people's well-beeing in accordance with the protection of the forests.

Thus, the summary of the literature not only bears witness to the scientific interest in the region but also to the decline of the forests, which already bore evidence of considerable anthropogenic encroachment when the first Europeans arrived. So far, plant communities have been described, and relations between vegetation and environment have been outlined based on observations alone. Only a few authors applied numerical methods to better describe those relations. The numerical methods used by the only early adopter (Bouxin, 1973, 1976, 1977) were state of the art in terms of the methods available at that time. Although giving important insights, the valuable work of Bouxin (ibid.) is restricted in the area of the survey and the capabilities of the methods accessible at the time. Habiyaremye (1997), the only other researcher that could be identified who used these methods, missed the opportunity to apply more appropriate and quantitative methods. Nevertheless, he was the first to apply multivariate methods to large parts of the Nyungwe, Gishwati and Mukura forests.

1.3 Description of the Study Sites

The Albertine Rift stretches from 30 km north of Lake Albert to the southern tip of Lake Tanganyika (Plumptre et al., 2007). Among others, the importance of the rift arises from the provided ecosystem services and the biodiversity it sustains. For higher taxa and ferns, Plumptre et al. (2007) stated the number of recorded species at 5793, 551 of which are endemic to the Rift.

The stretch of the Albertine Rift investigated is part of the equatorial tropics. The interannual shift of the Intertropical Convergence Zone brings about a climatic seasonality that largely manifests in the precipitation and cloudiness regime. Rainfall in Rwanda is divided into a major dry season between (June) July and August (September) and a minor dry season from mid-December to January (February) (Sun et al., 1996; Fischer & Hinkel, 1992). According to Kanyamibwa (2001), the rainy season lasts for nine months in the western parts of the montane forests. The annual average temperatures are at 15 °C to 21 °C throughout the country (Fischer & Hinkel, 1992). While the average maximum and minimum temperatures do not exceed 19.6 °C and 10.9 °C, respectively (Sun et al., 1996). Temperatures are moderated by altitude, which results in average temperatures of 0 °C at the top of Mt Karisimbi (Fischer & Hinkel, 1992). While pronounced diurnal fluctuations in temperature are a general feature of the montane rainforests along the Congo-Nile divide, regular frosts during the night are likewise experienced. Kanyamibwa (2001) gives an average annual rainfall of 600 mm for the east of the country to 1200 mm on the central plateau to 2400 mm for the

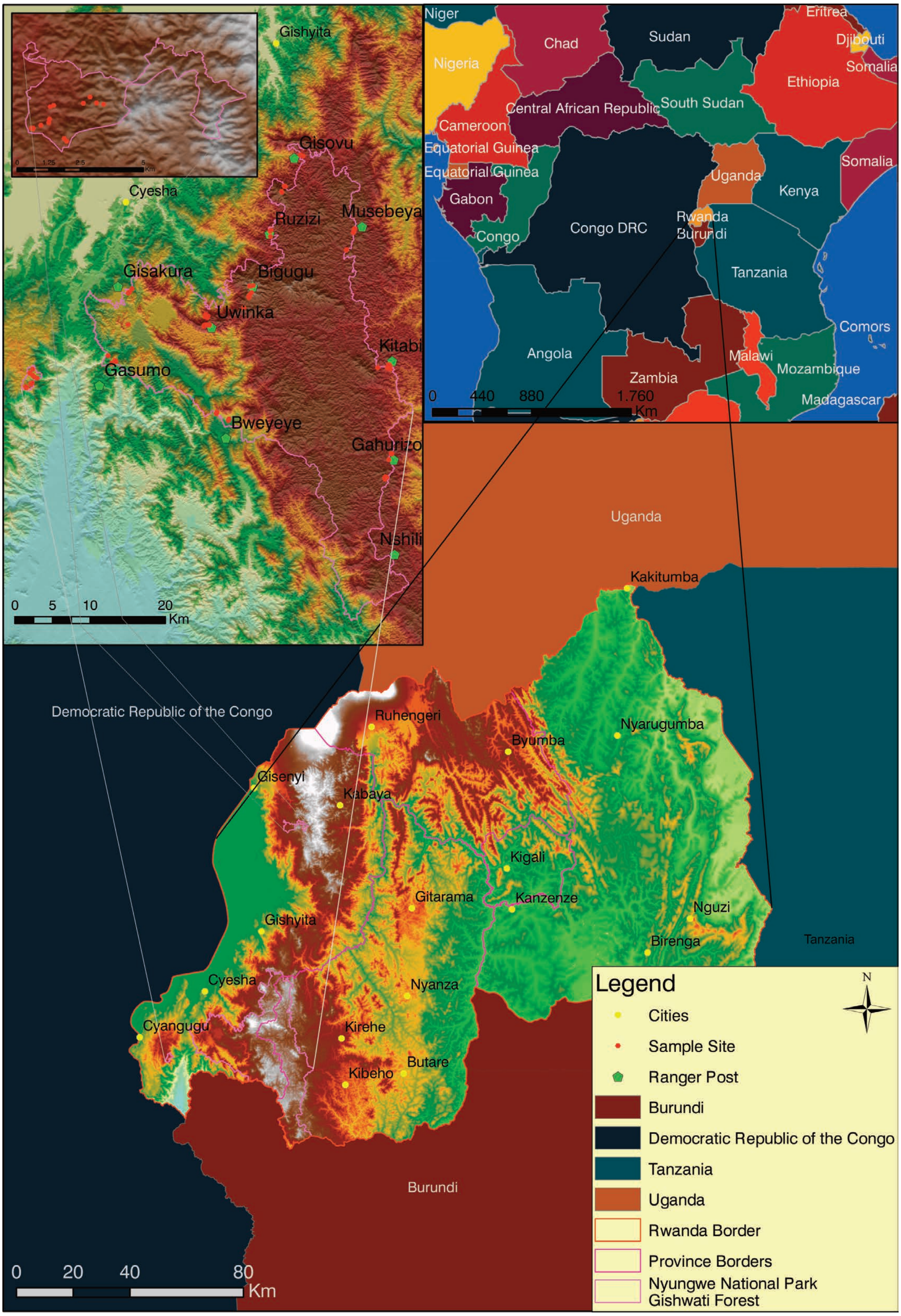

Figure 1.1: Location of Rwanda on the African continent. Locations of the forests in Rwanda and on the mountain range.

Congo-Nile divide. Within Nyungwe forest Nyirambangutse et al. (2017) measured an average precipitation of ~1657 to ~3016 mm (see Fig.1.3). Nyungwe National Park is divided by a part of the Congo-Nile watershed from north to south. This division is not only marked by contrasting precipitation regimes, but also by differing geologies, soils and altitudinal range. An altitudinal zonation dividing the vegetation of the forests into a lower level (1500-2100 m), a medium level (2100-2600 m) and an upper level (2600-2900 m) can be observed (Fischer & Killmann, 2008). Due to local topography, the ecotones between these zones may vary by 100 m (200 m) above or below the limits given afore (ibid.). The altitudinal range of Nyungwe forest is between (1400 m) 1600 and 2950 m a.s.l. (ibid.). In 2004 Nyungwe including Cyamudongo forest became a National Park comprising ca. 1010 km^2.

Cyamudongo forest is a remnant forest which has been isolated for more than 100 years form Nyungwe Fischer & Hinkel (1993). Its size amounts to 4 km^2. According to Fischer & Hinkel (1993) the elevation a.s.l. ranges between 1700 and 2140 m. The mean annual temperature measured as reflected by the soil temperature in 60 cm soil depth varies between 16-17 °C. Precipitation reaches an average of 1600 mm as interpolated from the data provided by the Rwanda Meteorology Agency and given in Nyirambangutse et al. (2017).

Like Cyamudongo forest Gishwati forest is situated on the Congo site of the watershed. Declared a National Park in 2015 its vegetation is heavily degraded and in 2007 the core forest only comprised 8.86 km^2 according to Nyiratuza, (2014). The altitude measured during the survey ranged between ~ 2000 to ~ 2400 m a.s.l. Mean annual temperature varies between 14 °C and 16 °C at least in the area surveyed. Mean annual precipitation as interpolated from data of the Rwanda Meteorology Agency is about 1400 mm.

1.4 Vegetation History

According to Sayer et al. (1992) the Rwandan mountains were part of the refugia for moist forest species during the dry climatic periods of the Pleistocene. During repeated climate changes the recolonisation of the savannah formations established during dry periods, originated from these relatively small refugia (Hinkel & Fischer, 1995). Within the refugia altitudinal shifts in vegetation zones as well as qualitative and quantitative changes in species range occurred during dry seasons (ibid.; see: Hamilton, 1982). While the forests form an archipelago-like disjunct area, the detachment of the forests entailed a separate evolution of the species. It follows that while the areas of the forests themselves are small they are spread over a wide range of topographic, edaphic and climatic conditions. This peculiarity results in an unusual species richness and high levels of local endemism coupled with species rarity (ibid., p. 102; see Hamilton, 1982). Albeit, a connection of some the forests along the Central African Rift and with some of the East African montane forests during climatic optima (12500B.P. and 6000 B.P.) was assumed by Hinkel & Fischer (1995). However, Poulsen et al. (2005) stated that species richness does not conform to simple models of Pleistocene refugia and assumed that it is current environmental factors that shape the patterns of species distribution to a large extent.

In accordance with own observations Nyungwe has been described as a dynamic mosaic of closed forest, secondary forest, drier forest ridges, swamp forest and large homogenous stands of bamboo (Sayer et al.,1992). It is believed that most of the openings and secondary forests are of natural origin, i.e., are due to landslides rather than human activities.

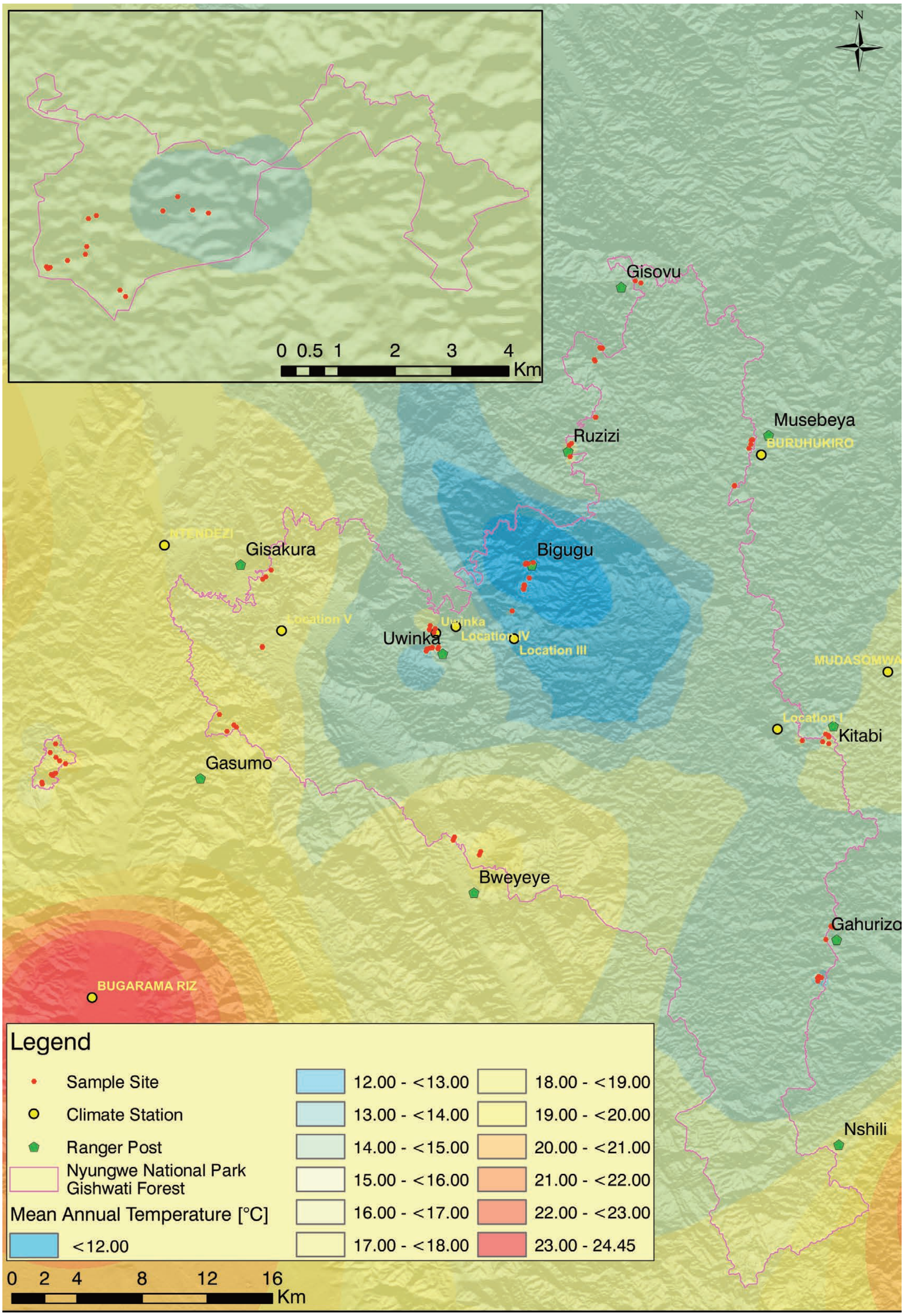

Figure 1.2: Mean annual temperature in the survey area. The data provided by the Rwanda Meteorology Agency and by Nyirambangutse et al. (2017) was interpolated using IDW in ArcGIs 10.3.

When it comes Gishwati forest far greater parts of the forest are of secondary nature and are more impoverished in terms of species richness (D'Huart, 1983) as cited in Sayer et al. 1992).

Following White (1983), the country is biogeographically situated at the convergence zone of at least four phytochoria: Guineo-Congolian Region, Zambezian-Region, Somalia-Masai Region and the Afromonatne Regional Centre of Endemism. Also elements of the Afroalpine vegetation and an influence of the Lake Victoria Regional Mosaic are common. Here, the author formulated that "the Lake Victoria Regional Mosaic is the meeting-place of five distinct floras: Guineo-Congolian, Sudanian, Zambezian, Somalia-Masai and Afromontane" (ibid., p. 181). Within the area of the survey, White (1983) differentiates three main vegetation units forests (Fig. 1.5). In their study of what Bizuru, Niyigaba, & Mujawamariya (2014) called Nyungwe montane savannahs, the authors classified the species found additionally into Cosmopolitans, Pantropicals, Paleotropicals, Afro-Malagasy, Montane Afromalagasy and Afro-tropical among others.

In Rwanda the mountains of the Albertine Rift hold the last closed canopy forests of the country. During history, all forests experienced a severe decline in area. Gishwati, Mukura, Nyungwe with Cyamudongo and the stands covering the Volcanoes have all been declared National Parks. Together they cover an area of 1221 km^2. Species diversity is high, with an estimated number of flowering plants of 2288 and an estimated number of vascular plants exceeding that. At least 26 vascular plants are endemic to Rwanda (Davis, Heywood, & Hamilton, 1994). For Nyungwe Forest Plumptre et al. (2007) gave the number of recorded species at 1105, 137 of which are endemic to the Albertine Rift.

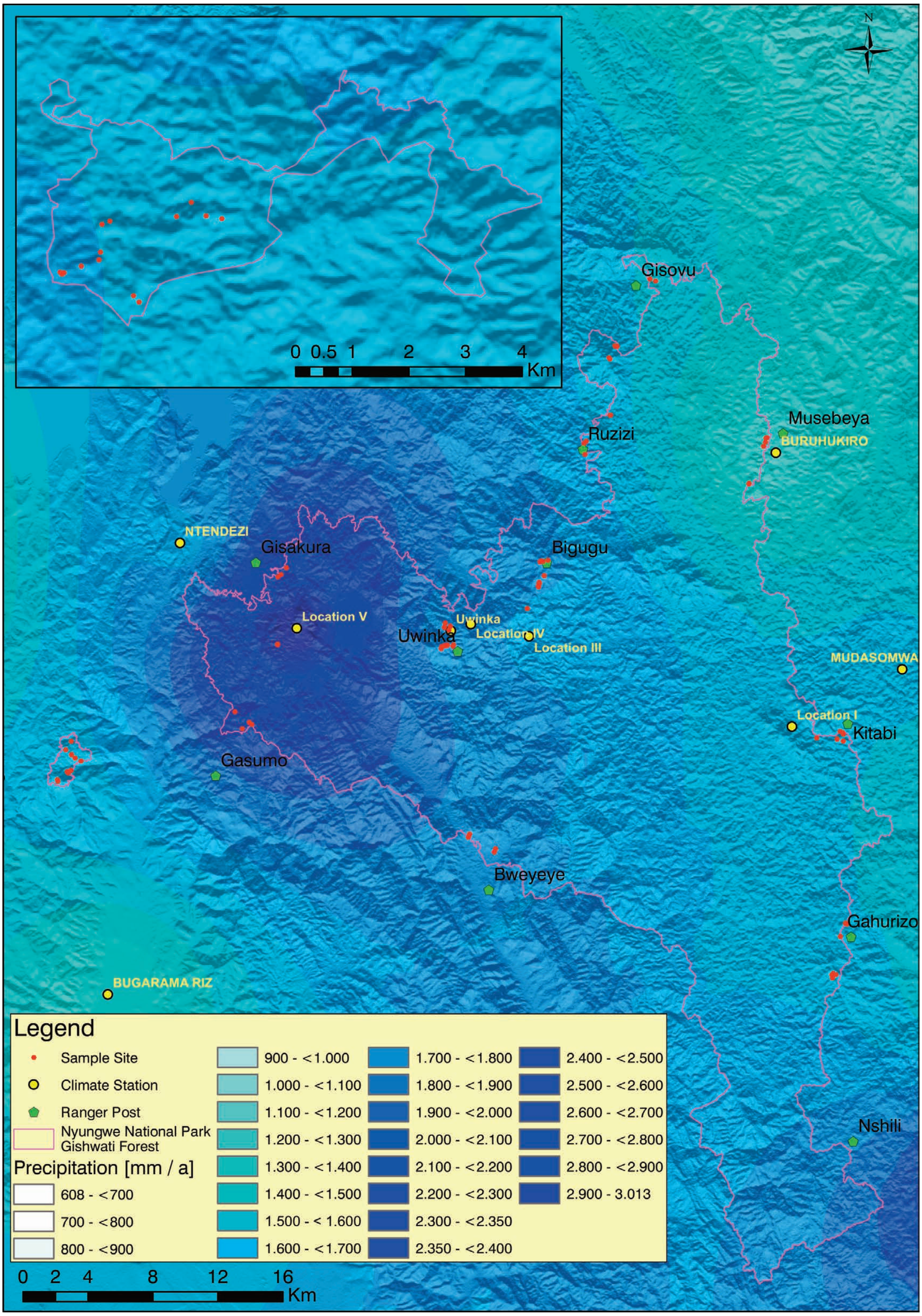

Figure 1.3: Mean annual precipitation in the survey area. The data provided by the Rwanda Meteorology Agency and by Nyirambangutse et al. (2017) was interpolated using IDW in ArcGIs 10.3.

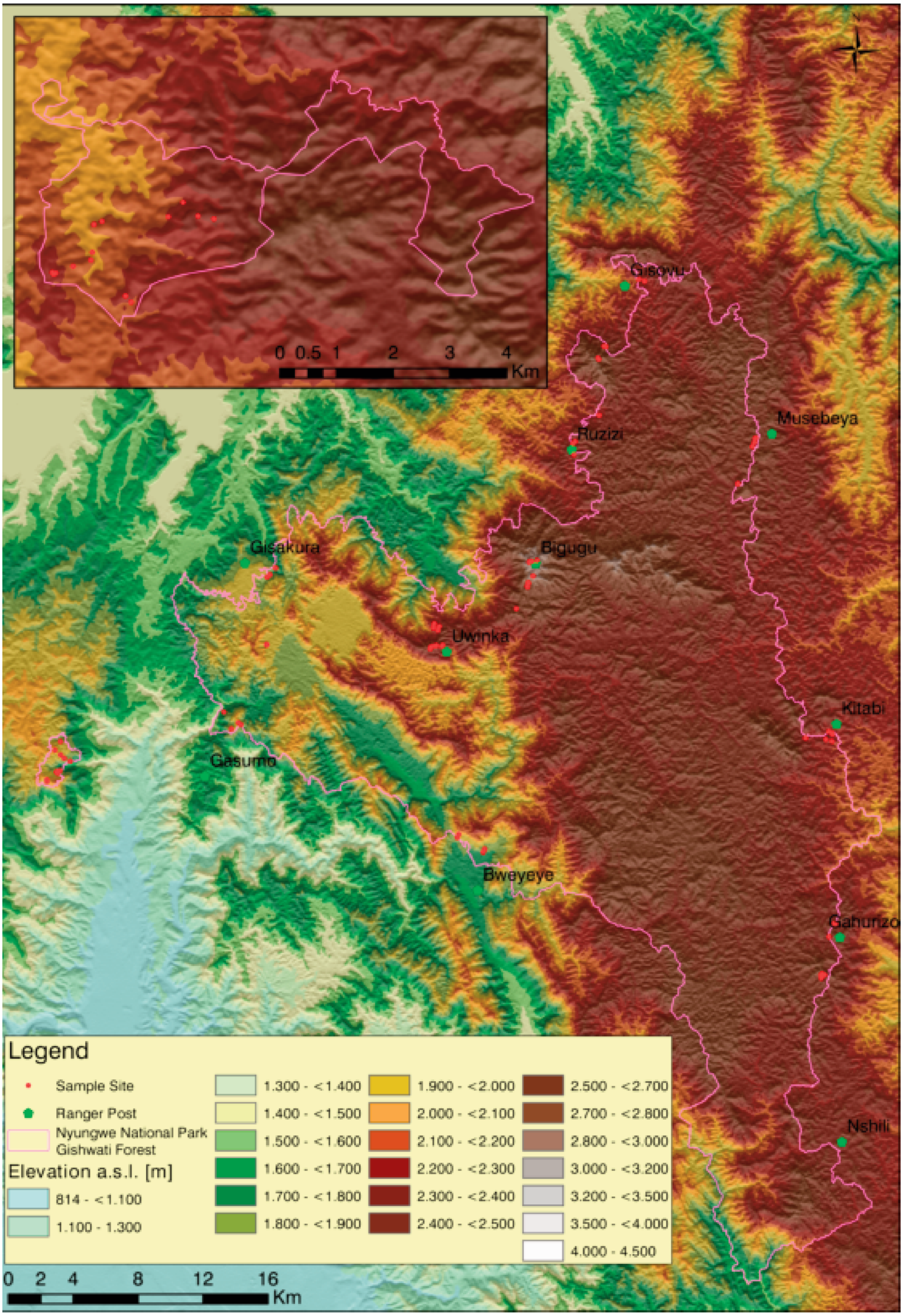

Figure 1.4: Relief and location of the survey areas.

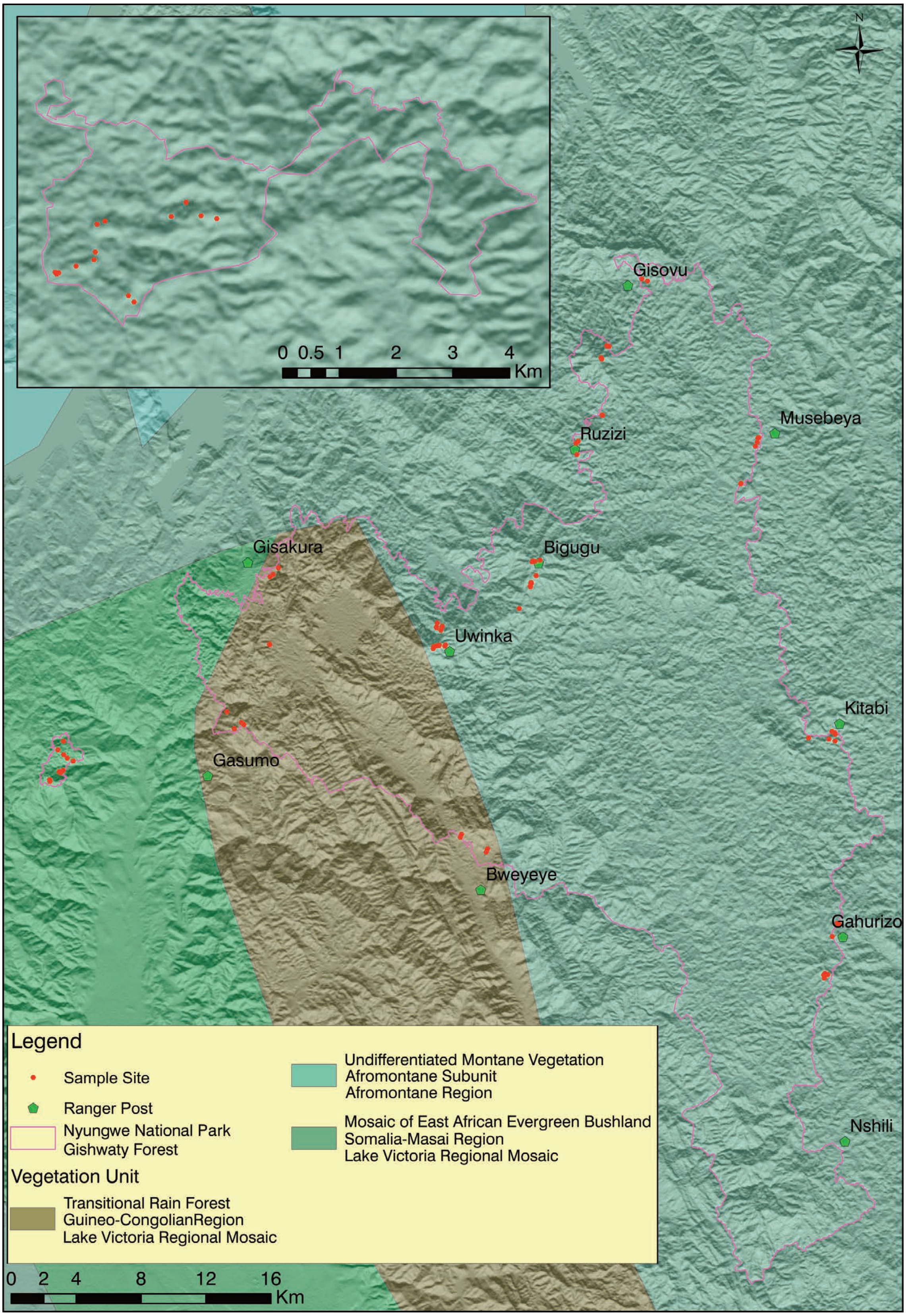

Figure 1.5: The main phytochoria that converge at the survey area, according to WHITE (1983).

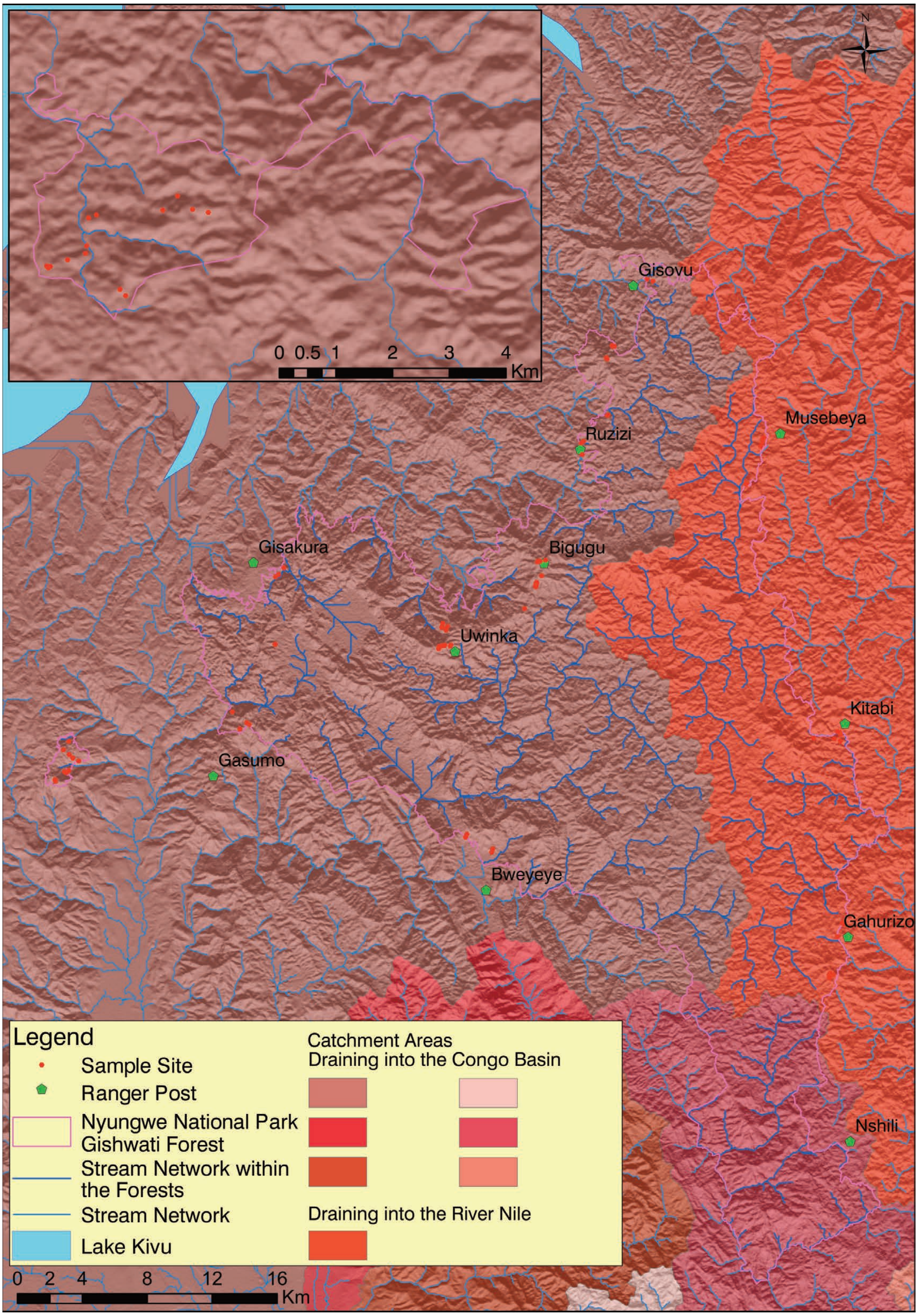

Figure 1.6: Divison of the catchment areas in the survey area.

1.5 Rational of the Survey

The justification for the survey is given by the section above especially by the last paragraph. It is long since known that the forests differ not only in species combination but in their environmental conditions as well. These facts have been observed multiple times and restated even more often. At least two researchers have given evidence to a variety of environmental factors impacting species composition and thus driving beta-diversity by using multivariate methods. Thus, substantiating the mere observations published before. The differences between the particular forests and in case of Nyungwe parts of the forest have been noticed as well and have been elucidated somewhat by HABIYAREMYE (1997).

The current survey attempts to quantify and partition the impacts of environmental factors on species combination. The differences between forests and their respective parts are sought to be outlined. The survey is aimed at being spatially explicit in terms of the impact factors and differences to be quantified. In order to do so, classification techniques will be applied prior to ordination methods to bring any differences and patterns in vegetation composition to light. In order to provide some more "tangible" form of beta-diversity, different measures of the relative change in species composition between locations will likewise be given. While species numbers and counts of other taxonomic levels have been evaluated, such numerical representations of beta-diversity have not been found in literature. The results may then be used to inform decisions in conservation management. First and foremost, the results should be used as input for future research appreciating the divergent conditions within and among the forests. Thus, realising not only the quantitative but the qualitative part in biodiversity. Moreover, the relatively coarse approaches of past surveys should be reviewed in respect to fine scaled occurrences of species and important environmental impacts overlooked. BOUXIN (1976) as well as EWANGO (2001) mentioned the time-consuming effort needed to evaluate the vegetation and its patterns. In the wake of the current developments all the parts of the forests, all the vegetation, all its patterns and changes therein have to be scrutinised at all spatial scales from broad to fine. The onset of changes in species distribution patterns will be gradually but steady with the changing climatological regime. The survey at hand tries to establish a baseline and to give hints on future research directions and requirements.

2 Material and Methods

In the sections below, the methods and materials used are introduced. The field and laboratory methods are discussed first, followed by the numerical methods.

2.1 Choice and Size of Sample Sites

There has been much debate on how to choose the sites from which to sample the vegetation to be surveyed, the discussion will not be outlined here. The belligerent reader may be referred to the article by LEPŠ & ŠMILAUER (2007) as well as ROLEČEK ET AL. (2007) and to consult PIELOU (1966). The study by MICHALCOVÁ, LVONČÍK, CHYTRÝ, & HÁJEK (2011) is likewise of interest in terms of the value of preferentially sourced vegetation data and the study of the species composition thereof. The position of the plots has been chosen in a preferential way. The digital elevation models available are rather coarse with a 90 m grid.

Thus, a priori planning of sample site location in the rugged terrain of the land of the thousand hills was a futile endeavour. The quite often long foot marches of several hours to reach accessible sampling locations were prohibitive to a larger extension of the survey area. The approach envisaged to investigate especially the impact of distance to the forest margin was stopped dead by the requirement to return to the same starting point every day. This stipulation also put an end to every figment of a random or at least stratified random sampling.

Despite the convention of 100 m² per sample being too small a sample size for a forest, especially for tropical rainforests, the given constraint of homogeneity within the plot counteracts larger plot areas in quite a few regions of the forest. Here, Bouxin arrived at a similar conclusion for his work from 1976. Albeit he has conducted his survey on relatively level grounds in a spatially restricted area, he came to the conclusion that 300 m² border on the largest possible area if one is concerned with matters of homogeneity within the plot. Since the survey at hand had been carried out throughout all kinds of terrain, matters of homogeneity within the sample area where aggravated. In some parts of the forest, around the ranger station at Bweyeye and at the sites towards mountain peaks for example, a 100 m² proved to be realised only with difficulties. Another point raised by Ewango (2001) is the time-consuming data collection in large plots (see also Bouxin, 1976). During his survey he was mostly concerned with tree and shrub species and still had to reduce his circular plots from 1200 m² to 314 m². In the present study all plant forms were surveyed and the 600 m² envisioned had to be given up very quickly due to both of the problems mentioned above. Even 200 m² were hardly feasible due to the time factor. Eligible sampling sites were further restricted due to the sometimes-inaccessible vegetation, be it because of steep slopes or the dense vegetation itself. Thus, 100 m² were chosen as a feasible plot size when considering all species present. The sample sites themselves have been chosen on the basis of homogeneity in terms of inclination, exposition, crown cover and conspicuously different vegetation within the plot. Any plot with an inclination that allowed standing and was accessible at least by climbing or crawling and without cutting a swath of destruction into the vegetation was eligible. No preference was made towards vegetation that appeared “typical” of the area. Thus, the method may be called subjective but without preconceived bias.

2.2 Sample Plots

In the current survey, hexagonal sampling sites have been employed to elucidate the spatial patterns and drivers of biodiversity in tropical montane cloud forests in Rwanda. The advantages of a hexagonal sampling design have been clearly outlined and exhaustively discussed by Jurasinski (2007). A sparse restatement of the benefits can be given as follows: the nested sampling plots are all equidistant and hence allow for detailed and spatially explicit assessments of biological diversity, while circumventing problems in calculating and evaluating diversity measures caused by inconsistencies in sample spacing. The isodiametric plot shape results in a smaller perimeter-to-edge ratio and thus minimises vegetational heterogeneity, in other words, fewer edge effects are brought about by specimens that are only partially within the plot. Furthermore, the hexagonal sampling design is easier to establish in the field than a circle. The envisaged grid design could to be achieved due to the terrain features and the restrictions given by the local authorities. In the field, sample plots were marked using brightly coloured rope and warning tape. The triangular subplots were aligned using a compass (RECTA GS50G).

Samples were taken in the vicinity of the respective ranger stations throughout Nyungwe forest. For Cyamudongo forest the only station there has been the base camp. For Gishwati forest the office of the Forest of Hope Association provided the starting point.

Ranger Post Forest		Uwinka	Gisovu	Gasumo	Ruzizi	Bweyeye	Gisakura	Bigugu	Gahurizo	Kitabi	Musebeya
		U	G	Gs	R	Bw	Gk	B	Ga	K	M
Gishwati	Gw	-	-	-	-	-	-	-	-	-	-
Cyamudongo	C	-	-	-	-	-	-	-	-	-	-
Nyungwe	N	NU	NG	NGs	NR	NBw	NGk	NB	NGa	NK	NM

Table 2.1: Coding of the sample sites in reference to the location in the respective forest and in relation to the nearest ranger station.

In the following the sample sites are coded according to the respective closest ranger station and the respective forest. The abbreviations can be taken from Table 2.1, enumeration is continuous.

The term primary forest is used only when previous descriptions have referred to the vegetation type as primary. The notation seems rather disputable in view of the active landscape and the long history of settlement. It cannot be accounted for the time it takes until climax species dominate a once burnt site or a site impacted by a landslide, but it stands to reason that not every bit of apparently pristine forest is of primary nature.

In the previous sentence, the word climax has been used. This may unsettle some authors, but the dispute revolving around that issue will not be discussed here any further. Climax is used here in the sense that species forming vegetation stands which, without anthropogenic impact or any other catastrophic event will eventually dominate the vegetation for a longer period than any other successional state, i.e., assembly of plant species. This does not necessarily include a deterministic process, neither when it comes to species composition nor to duration of the previous but still transient states.

2.2 Vegetation Data

All vegetation strata have been recorded including all plant types and species. In the case of woody species, only plants with a dbh starting from 1 cm were sampled. According to CHAVE (1999) and KÖHLER (2000), this approach reflects successful reproduction including seed survival, germination and possible predation on young seedlings. The height of the respective vegetation strata was either measured or estimated using a clinometer and a tape measure. The percentage ground cover was estimated using the estimation tool given Annex 1. The surrounding forest matrix adjacent to the samples was ascertained either on site or by evaluating satellite imagery in ArcGIS 10.3 by ESRI. The same procedure was followed for the distance to the forest edge. The matrix categories can be obtained from Table 2.2.

Forest Matrix	Abbreviation
Tree Plantation	TreePlnt
Tea	Tea
Road through Forest	throuRoa
mosaique Tree Tea + Earth Road	eRmosTT
mosaique Tree Tea	mosTT
Earth road + Tree + Village	eaRoTrVi
Earth road + Tree	earRoaTree
other	other
Uwinka	Uwinka
Road through Forest + Tree + Tee	eaRotrTT
narrow Tree + Tee	naroTrTe
Earth Road on Edge + Tree Pasture mosaique	erRoTPmo
Tree Pasture mosaique	mosTrPas
more than 300m	abv300
Earth Road through Forest	trghRoEa
natural interior edge	natintEg

Table 2.2: The forest matrix types closest to the respective samples. Matrix types were determined on site or via satellite images in ArcGIS 10.3.

2.2.1 Abundance Measure and Estimation Scale

As a proxy for abundance, i.e., the count of individuals, percentage ground cover has been chosen to provide an insight into the structure of the stands surveyed. Counting individuals seemed fraught with arbitrariness; deciding which of the species does not spread vegetative and which “individuum” is not the others ramet or genet could not be decided in the field. LONDO’S (1976) decimal scale seemed appropriate due to the fine scale and the reduced need to transform values as to be utilised in different software not apt to process the gradation in the form of letters and symbols especially in the lower percentage categories comprising a coarse approximation of individual counts. The scale devised by LONDO (1976) is given in Table 2.3 with a comparison to the scale constructed by BRAUN-BLANQUET (as cited by LONDO, 1976).

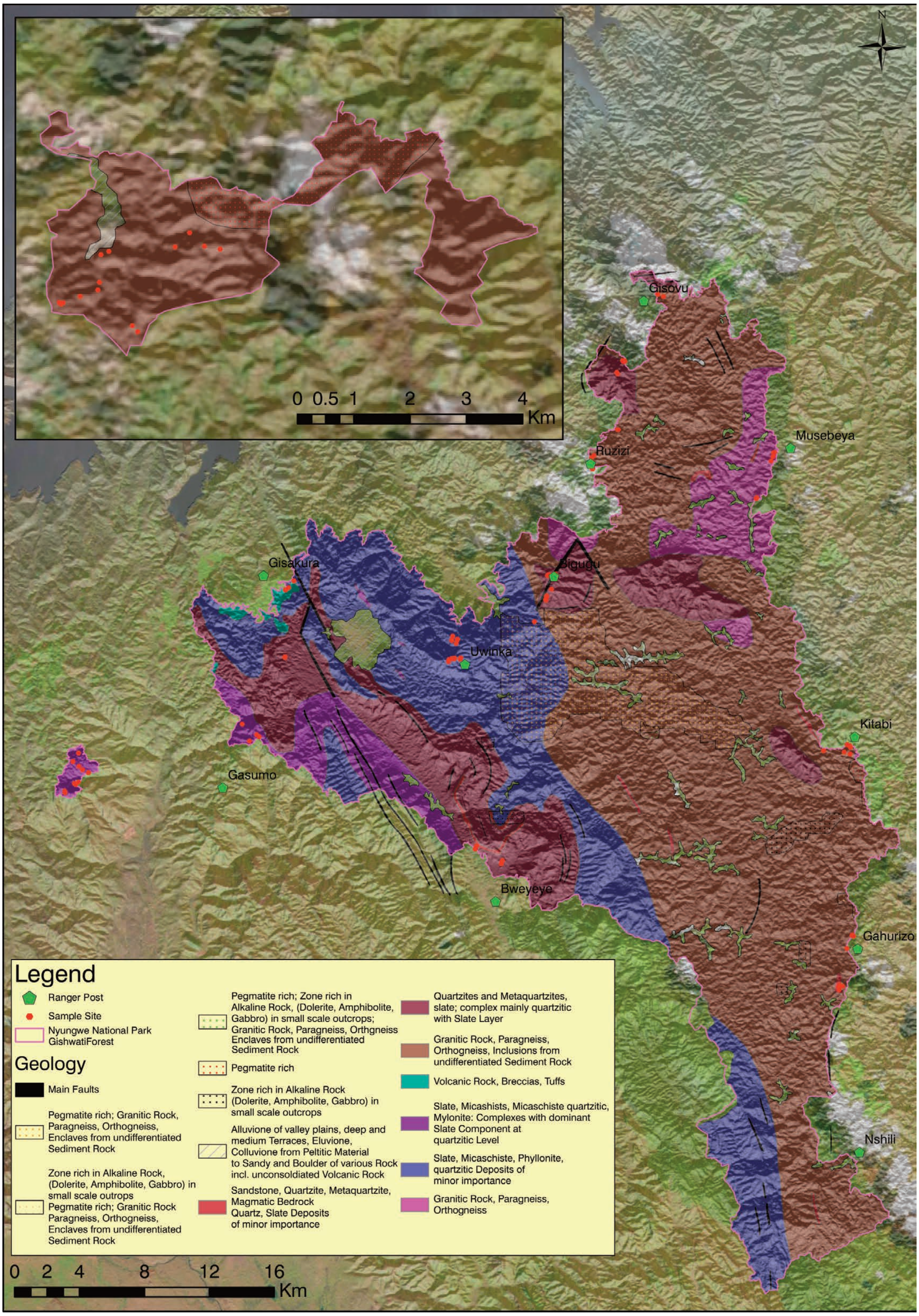

Figure 2.1: Geology of the survey area. The data was digitalised based on the *Carte Lithologique du Rwanda* by the *Institute Géographique National de Belgique* (1981).

Symbol	Cover	Additonal Symbols	Braun-Blanquet Scale
0.1	< 1%	. = r (raro) p (paululum)	+
0.2	1-3%	a (amplius)	1
0.4	3-5%	m (multum)	
1	5-15%	1- = 0.7 = 5-10% 1+ = 1.2 = 10-15%	2
2	15-25%		
3	25-35%		3
4	35-45%		
5	45-55%	5- = 45-50%	
		5+ = 50-55%	4
6	55-65%		
7	65-75%		
8	75-85%		5
9	85-95%		
10	95-100%		

Table 2.3: Estimation scale according to Londo (1976). Simple Braun-Blanquet scale given for comparison (LONDO, 1976)

2.2.2 Identification of Plant Species

The following literature was used for plant species identification:

“Flore du Rwanda, Spermatophytes”, Volume I (TROUPIN, 1978)
“Flore du Rwanda, Spermatophytes”, Volume II (TROUPIN, 1983)
“Flore du Rwanda, Spermatophytes”, Volume III (TROUPIN, 1985)
“Flore du Rwanda, Spermatophytes”, Volume IV (TROUPIN, 1988)
"Upland Kenya Wild Flowers" (AGNEW & AGNEW, 1994)
Flora of Ethiopia and Eritrea Volume 7 Poaceae (Gramineae) (HEDBERG & EDWARDS, 1995)
"Flore d'Afrique centrale" (Flore du Congo belge et du Ruanda-Urundi 1948 - 1960)
Flore du Congo, du Rwanda et du Burundi 1963-1971
Flore d'Afrique centrale (Zaire-Rwanda-Burundi) seit 1972)
"Flora of Tropical East Africa" (FTEA) (TURILL ET AL. 1952-1990)
"Flora Zambesiaca, Pteridophyta" (SCHELPE 1970);
"Pteridophytes of Tropical East Africa- A Preliminary Checklist of the Species" (JOHNS 1991);
Cyperaceae und Juncaceae:
"The Sedges and Rushes of East Africa" (HAINES & LYE 1993)
"Flora of Tropical East Africa" (FTEA) (TURILL ET AL. 1952-1990);
"An Illustrated Guide to the Grasses of Uganda (HARKER 1960);

The nomenclature was predominantly adopted from the Kewscience platform Plants of the World online (POWO, 2019).

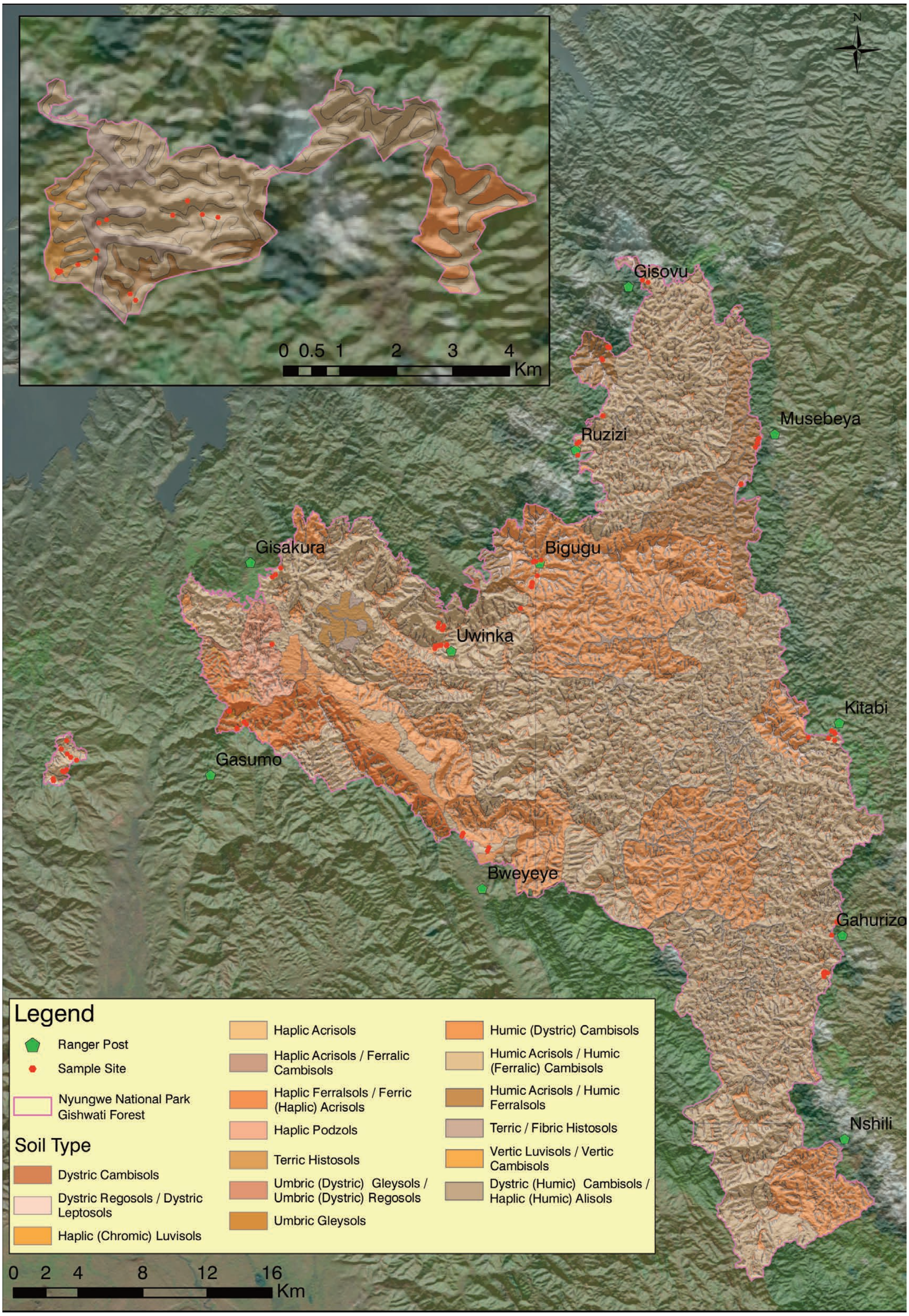

Figure 2.2: The soil types in the survey area. The data was provided by the GIS centre of the University of Rwanda.

2.3 Environmental Data

In the following the environmental data measured and assessed will be listed and the methods of analyses will be given. In order to ensure a better clarity of the interrelationships in the analyses and evaluation, the environmental factors surveyed were divided into two groups. The first group is referred to as environmental variables (where necessary indicated by s. str.) and includes climate factors and terrain properties. The second group includes all soil properties and is referred to as soil variables in the following. Where necessary, environmental factors are referred to as s.l., in which case the totality of independent variables is addressed.

Geology	Abbreviation
Granitic Rock, Paragneiss, Orthogneiss	GranitePara
Granitic Rock, Paragneiss, Orthogneiss, Inclusions from undifferentiated Sediment Rock	GraniteSedi
Quarzites and Metaquarzites, Slate; complex mainly quarzitic with Slate Layer	Quarzitic
Sandstone, Quarzite, Metaquarzite, magmatic Bedrock, Quartz, Slate Deposits of minor importance	Sandstone
Slate, Micaschists, Phyllonite, quarzitic Deposits of minor importance	SlateMylo
Slate, Micaschits quarzitic, Mylonite: Complexes with dominant Slate Component at quarzitic Level	SlatePhyllo
Volcanoc Rock, Breccias, Tuffs	Volcanic

Table 2.4: The Geology present at the sample sites as determined by the *Carte Lithologique du Rwanda by the Institute Géographique National de Belgique* (1981).

Soiltype_FAO	Code
Dystric Regosols / Dystric Leptosols	DRDL
Humic Acrisols / Humic Ferralsols	HAHF
Humic Acrisols / Humic (Ferralic) Cambisols	HAHFC
Haplic (Chromic) Luvisols	HCL
Humic (Dystric) Cambisols	HDC
Haplic Ferralsols / Ferric (Haplic) Acrisols	HFFHA
Terric / Fibric Histosols	TFH
Vertic Luvisols / Vertic Cambisols	VLVC

Table 2.5: The soil types present at the sample sites. Nomenclature according to WRB (FAO) (2008)

The climatological data were kindly provided by the Rwandan Meteorology Agency, measured either directly in the field or derived by GIS based interpolated maps. Mean annual temperature 2 m above the ground is reflected by the temperature in 60 cm soil depth (Richter, 2003). Soil temperature was measured accordingly with an analogous soil thermometer of an unknown brand. The map of the mean annual temperatures is based on the measured soil temperatures, the data given in Nyirambangutse et al. (2017) and the data provided by the Rwandan Meteorology Agency. The ArcGIS 10.3 software by ESRI was used to interpolate the surface by inverse distance weighting (IDW). The precipitation map was prepared in a similar way. Here, the basic data was provided by the Rwandan Meteorology Agency and adapted from the work of Nyirambangutse et al. (2017).

German Origin	Translation	Symbol
sandiger Lehm / Sand 25-63%	Sandy Loam	Ls 2-3
sandiger Lehm / viel Feinsubstanz	Sandy Loam / Much Fine Substance	Ls4
tonig sandiger Lehm	Clayish Sandy Loam	Lts
schluffiger Lehm	Silty Loam	Lu
lehmiger Sand	Loamy Sand	Sl
toniger Sand	Clayish Sand	St
schluffiger Sand	Silty Sand	Su
(lehmiger) Ton	(Loamy) Clay	T(l)
sandiger Ton	Sandy Clay	Ts
sandiger Schluff	Sandy Silt	Us
toniger Schluff	Clayish Silt	Ut

Table 2.3: The soil textures encountered. Categories are according to Blume et al. (2011).

German Origin	Translation	Symbol
Kulminationsbereich	Culmination area	K
Tiefenbereich	Depth area	T
Hang	Slope	H
Mittelhang	Middle Slope	HM
Oberhang	Upper Slope	HO
Unterhang	Lower Slope	HU
		HU/HM
hängiger Kulminationsbereich	Sloping Culmination Area	KH
gerundeter Kulminationsbereich	Rounded Culmination Area	KM
stark gewölbter Kulminationsereich	Strongly Curved Culmination Area	KR
ebener Kulminationsbereich	Level Culmination Area	KS
ebener Tiefenbereich	Level Depth Area	TS

Table 2.4: Relief form categories as found at the samples sites. Categories are according to Blume et al. (2011)

Surface	Category
Even (≤ 6 roughnesses)	1
Uneven (≥ 7 roughnesses)	2
Boulder Field	3
Coarse Surface with Vertical Walls, Clefts and Cliffs	4

Table 2.5: Surface type categories. A roughness is defined to deviate more than 0.35 m from the surrounding terrain surface. Categories are adopted from Bendiksen et al. (2007).

Terrain Form	Category
Valley Bottom or Concave Terrace	0
Concave Valley Side	1
Plane Valley Side	2
Convex Valley Side	3
Ridge	4
Hilltop	5

Table 2.6: Terrain form categories. The categories were adopted from Økland & Eilertsen (1994)

Exposure and inclination were determined using a Recta DS50G compass and clinometer. The geographical position and altitude a.s.l. were measured utilising a Garmin GPSMAP 62s. The terrain form was assessed visually using the categories given in Blume, Stahr & Leinweber (2010). The parallel and transverse slope curvature was visually assessed gauge in the two categories convex and concave. The surface of the sample side was judged on vision and were necessary measured by tape measure.

The point solar radiation was calculated using ESRI's ARCGIS 10.3 based on a digital elevation model (DEM) derived by ASTER imagery provided by the NASA Earth Observatory. A map of the soil types was provided by the friendly people of the GIS centre of the Rwandan National University. The geological map was digitalised by hand in ArcGIS 10.3 based on the *Carte Lithologique du Rwanda by the Institute Géographique National de Belgique* (1981). The Topographical Wetness Index (TWI) was calculated in ArcGIS 10.3 by ESRI based on the above-mentioned DEM, the interpolation is based on IDW.

Soil properties were also recorded directly on site. The soil type was classified using the identification key given in Blume et al. (2011, p. 21). Drillable soil depth was estimated using an Eijkelkamp auger and a tape measure. The stone content of the soil was estimated from a sample taken by a spade sample (Spatenprobe) according to Görbing & Sekera (1947). Undisturbed soil samples for chemical analyses were taken from the A-horizon ($\sim$15cm) using soil sample rings by Eijkelkmap in all of the six subplots and subsequently pooled. The soil samples were dried in a memmert universal oven at 110 °C for 16 h.

Analyses of chemical soil properties were carried out at the laboratories of the Department of Geography at the University of Koblenz-Landau. All samples were sieved (< 2 mm) and homogenised in a porcelain mortar. The pH-value was measured by repeated shaking (2h) of 1g sample in 2.5 ml 0.01 mol/l $CaCl_2$ on a Hanna Instruments pH211 using a WTW SenTix 22 electrode. Electrical conductivity in μS was measured in the same solution using a conductivity electrode (VWR International CO310).

In order to determine the effective cation exchange capacity, an aliquot of a respective soil sample was ground in a ball mill. The exchangeable and hence ecological relevant cations were extracted according to DIN ISO 19730 (2009) by repeated shaking (1 h) of 5 g of each sample in 1 molar NH_4NO_2. The extracts were separated from the samples by filtering through a pleated filter. Subsequently, the cation exchange capacity was determined by summarising the concentrations of the cations of Al, Ca, H, Mg, K, and Na. The metal concentrations were analysed by atomic absorption spectroscopy (AAS) using a PerkinElmer Aanlyst 400 Atomic Absorption Spectrometer. The molarity of dissolved H of each extraction was calculated using the formular: CH = 10-ph.

The concentration of extractable phosphate (PO_4^{3-}) was determined using the double-lactate extraction method according to Blume et al. (2011). For this purpose, 15.5 g of Ca-lactate and 7.9 g of Ca-acetate were dissolved in 1 litre of H2O and adjusted to pH 4.1 with acetic acid. From each sample, 5 g were shaken in 100 ml of this solution (1.5 h), filtered and analysed by continuous flow analysis (CFA) (Bran + Luebbe Auto Analyzer 3 (now Seal Analytical)) at 882 nm after pre-reaction with NH4+-molybdate. The contents of organic carbon (C_{org}) and total N (N_t) were analysed after combustion (950 °C) by a C/N analyzer (Vario ElCube Elementar, Langenselbold, Germany).

2.4 Compilation of Species Communities

Numerical classification methods are used in the present work. Among the reasons that led to this choice is the need to minimise subjective decisions in the process of setting up vegetation communities. Moreover, the sampling plots were small and their distribution was restricted from the outset by the guidelines of the local park administration. The resulting undersampling would consequently have led to unstable results and vegetation units in the sense of BRAUN-BLANQUET would have been construed only by force as the basic prerequisites for the correct application of the system were not given.

The classification undertaken here, is based on mostly objective methods and should not be juxtaposed to the classical approach in which vegetation consists of discrete, integrated units (see MCINTOSH, 1967). In difference to MCINTOSH (1967, p. 133), community will be used in the following as an abstract grouping of concrete stands in the real world which exhibit a species combination so similar that it seems not without reason, to group them together and classify them under a name describing their nature to the reader. It is understood that this application of the term also applies to the larger scale and therefore less detailed higher syntaxonomic level. In using the term community, it was also considered that, although plant sociological work has been carried out in the region, the overall rank of the species characteristic of the communities constructed here, in the plant sociological system is not adequately known outside the study area.

The often-high species richness and, for most of the species, low abundances in the samples, complicated the construction of vegetation units even when using numerical methods. For challenging cases, abundances, in this situation its proxy percentage ground cover, decided on the establishment of a community, however preliminary. The morphology of the stand, at the very least tree height, the history as far as reconstructable and, following from this, the current state of the site affected the inductive formation process of a phytocoenon if necessary as well.

Like GLEASON (1939) acknowledged recurring patterns in vegetation and GOODALL (1963), as cited in: MCINTOSH, 1967) stated that a continuum of (partly) individualistic communities can be classified in a variety of ways, so is the classification proposed here set in the realisation of a continuous change in vegetation which only rarely is disrupted by sharp changes. Albeit one's is not entirely arbitrary, the notion of CURTIS (1959), that an arbitrary classification of a continuum is possible and sometimes useful and desirable, shall be the guiding thought here. The (mostly) objective methods used, shall mitigate the discord with good scientific practice.

However, the existing phytosociological works are all based on BRAUN-BLANQUET'S system, so it follows that the units resulting from the application of the numerical methods are compared with the existing formations and an attempt is made to place them in the existing system.

2.5 Cluster Analyses

To illuminate the structure of the vegetation patterns found, a couple of clustering techniques have been employed. Two density-based algorithms, DBSCAN (density-based spatial clustering of applications with noise) and OPTICS (ordering of points to identify the clustering structure), were selected to find out if any non-spherical or nested patterns are present in the data (HAHSLER ET AL., 2017). In a different approach, a Gustafson-Kessel-like fuzzy c-means algorithm with entropy regularisation and a noise cluster was put to use to find nonsperical clusters of arbitrary forms as well. All of the options failed to result in ecologically and syntaxonomically meaningful clusters. However, in the style of Bezdek (1981, p. 103), if the method used does not reach a valid solution, we do not presume that X has no identifiable substructure; rather, the algorithms used have not found any! For the data at hand, two traditional methods resulted in revisable and conclusive vegetation units.

Unweighted arithmetic average clustering (UPGMA) was used as a hierarchical option. The fuzzy c-means with noise clustering (FCM-NC) has been used as a non-hierarchical means in order to discover if and how species groups overlap, i. e., how diffuse the boundaries between communities are. The fuzzy algorithm has been adjusted by an option to find outliers. The similarity of which to others is too small to establish a compact cluster. First, a comparison will be drawn between UPGMA and FCM-NC. The intrinsic hierarchy in UPGM will be dealt with later.

2.5.1 Unweighted Pair-Group Method using Arithmetic averages

The UPGMA approach does not rely on the links between clusters and is not an object-linkage method (Legendre & Legendre, 2012). Instead, it calculates the average distances among objects or the centroids of the clusters (ibid.) In the "Unweight Pair-Group Method using Arithmetic Averages" the lowest distance identifies the next cluster to be formed. In the next step, the arithmetic average of the distances between a candidate object and each of the cluster members is calculated. All objects receive equal weights in the calculation. At each clustering step, the distance matrix is updated and reduced in size. The clustering process progresses in an agglomerative way with the distance criterion increasing (Legendre & Legendre, 2012, p. 353). The method, as implemented in PC-Ord (McCune & M. J. Mefford, 2018), results in a dendrogram with a scale based on Wishart's (1969) objective function, which is not a simple distance measure. What is measured is the loss of information as agglomeration proceeds (McCune & M. J. Mefford, 2018); whereby, the sum of error sum of squares from each centroid to the items in that group is calculated by the objective function. Also, the dendrogram is scaled by the percentage of information remaining after the subsequent group has been fused. When all items have been fused into one group, none of the information remains. The objective function and the pseudoalgorithm of the agglomerative process can be found in Wishard (1969, p.168).

2.5.2 Fuzzy C-means with Noise Clustering

According to Jain & Dubes (1988, p. 90), k-means partitioning solves the problem of partitioning n given patterns in a d-dimensional metric space into K groups, or clusters, such that the patterns in a cluster are more similar to each other than to patterns in different clusters.

Since natural species communities were surveyed in situ, a certain overlap of communities had to be presumed; this meant that the crisp clusters derived by k-means would not match natural conditions. Thus, Zadeh's (1965) fuzzy sets were invoked. As stated in Zadeh (ibid.), a fuzzy set is a class of objects with a continuum of grades of membership which may vary between zero and one.

The basis for the development of fuzzy sets was the objective functional given in Bezdek (1981, p. 54) which generates hard clusters in space X. The overall within-group sum of the squared errors (WGSS) functional given in Jain & Dubes (1988), is also a measure of the cluster quality in that an extremum of the function or some derivative of it (large change or jump in slope) is taken as the most valid clustering (Bezdek, 1981). The variable J_W assesses (Bezdek, ibid., p. 54) the dissimilarity between single data points x_k and cluster prototypes v_i not necessarily in X. The aim of the operation is to minimise J_W, which is achieved when each u_i adheres tightly to its cluster centre v_i,i. e., d_{ik} is small. The *i* th term in in the formular is the sum of the within-cluster squared errors over all the x_k's ϵ u_i (Bezdek, 1981). The within-cluster squared errors should thus be small in contrast to the variance between clusters. According to Jain & Dubes (1988, p. 96-97), following the pseudoalgorithm they provided minimises the objective function and may lead to a global minima in the objective function.

Since the mountainous survey area offers a plethora of habitats, it had to be taken into consideration that there are sample sites with vegetation that largely differs from the others and that an assigment to a syntaxonomic unit would have been somewhat arbitrary. The fuzzy c-means algorithm, as implemented in the R-package vegclust (De Caceres, 2016), offers the possibility of noise clustering. As stated in Davè & Krishnapuram (1997) (see Davè 1991), noise in a data set could be considered as a class of its own, which is represented by a prototype that has a constant distance (**Δ**) from all data points in the set. If a suitable value for said distance can be found, the noise clustering version of the FCM approach is less sensitive to noise and outliers. This outcome is achieved by relaxing the constraint on the memberships so that the sum of memberships of a noise point in all good clusters is not forced to be equal to one, i.e., the membership values for outliers in all good clusters can be arbitrarily small (Davè & Krishnapuram, 1997, p. 273).

The R-package vegclust offers the possibility of working with either centroids or medoids. In the analyses, the centroid approach has been employed. In order to get a starting point for the cluster number, global cuts at different information levels of the UPGMA derived dendrogram have been used to approximate a reasonable cluster number. The parameter dnoise, i.e., the distance from which the data points were considered to be noise, was determined by running a FCM first and subsequently averaging the within sum of squares of the clusters. The square root from this average was taken as an approximation of the noise distance parameter (pers. communication De Caceres, 2018).

Davè & Krishnapuram (1997, p. 273, Formular (9)) provided an objective function for the fuzzy c-means clustering with noise clustering. By modifying the exponent m the "fuzziness" of the membership assignments can be regulated. In other words, weighting exponent m, controls the extent of membership sharing between fuzzy clusters within the given patterns (see Bezdek, 1981). The choice of suitable values for m, so far, is without a theoretical basis (Bezdek, 1981, p. 70). According to Li & Mukaidono (1995, p. 2227), FCM as introduced by Bezdek, is a "wonderful method because Bezdek introduced a 'strange number' m." Within the same source, some problems are listed as to the meaning of m and how an optimal choice is made. Also, the question of how to achieve global minimum solutions (for WGSS) is left unanswered.[2]

In practice, the choice of m is made rather explorative. Since the value for dnoise also depends on the size of the value for m, two indications to suitable values are given by the results of a vegclust run. Firstly, with increasing m, the membership values become more and more equal for the given clusters for each data point, i.e., if the sampling sites

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[2] Consideranto: "A difficulty […] concerns the fact that objective functions usually have multiple local stationary points at fixed c, and global extrema are not necessarily the "best" c-partitions of the data." (Bezdek, 1981, p. 96)

have equal memberships for each cluster, the fuzziness value might be too large. Secondly, if the distance from which a data point is considered noise is chosen to small, the noise cluster tends to be the largest cluster. In both cases no meaningful classification could be achieved even if the data contained discernible patterns.

If a non-Euclidean distance measure has been chosen to delineate differences between samples, FCM will give a distorted result due to its inherent Euclidean metric. In order to obtain an undistorted outcome, in this case, for the percentage difference as a dissimilarity index, one has to compute a PCoA (principal coordinates analysis) on the square root of the dissimilarity matrix. Only then will a fully Euclidean solution be attained. The R-package vegclust (De Caceres, 2016) offers the option to circumvent the PCoA detour in that it allows for direct input of distance matrices stemming from any distance or dissimilarity measure via the function vegclustdist() (De Caceres, 2016).

As Bezdek stated (1981, p. 96), the subjective element injected into most final judgments is not bad, "[…] computers can be used for advice, but the investigators should call on their special knowledge of the data to ask: is this algorithmically suggested substructure reasonable for our data?" Additionally, in keeping with Bezdek (ibid.) and Kant (1784), the results of several runs with all possible combinations of cluster number, fuzziness exponent m and dnoise have been scrutinised, compared to the recorded vegetation and set into relation to the actual Bray-Curtis values. For the present work, the choice as to a pair of values for m and dnoise as well as to a suitable cluster number has been made also in comparison with the results obtained by UPGMA. The most actualised result of the test series has been chosen.

None of the methods offered to globally cut the dendrogram derived via PC-Ord is free of the impact of environmental variables. Since the aim of the classification effort made here is to find similarities between samples on the basis of compositional similarity only, another solution was applied. Since the indicator species analysis of PC-Ord likewise gave unsatisfactory results, the choice of the global cut level has been taken on an informed basis guided by species overlap and the respective abundances as well as by Bray-Curtis values.

In order to get an objective result, a second FCM-NC has been carried out on the basis of the communities established before. This rendered the Bray-Curtis measure inapplicable. Instead, the probabilistic Raup-Crick (Raup & Crick, 1979) index was used to account for the unequal sampling efforts. The index was calculated assuming that the probability of selecting a species corresponds to its frequency (Oksanen et al., 2018, p. 222). In the same manner as before, the results of UPGMA and FCM-NCRC have been compared and an according pruning level has been set.

2.6 Ordination Methods

In 1929, Ramensky made the point that only the "Coordination" of species around the ecological mean could adequately represent the continuous quality of the vegetation cover. Most often it is the predominant effect of only a few factors that are interrelated in a multidirectional way that allow one, by performing a series of successive approximations and by utilising all the samples, to uncover the principles governing vegetation composition (ibid.). He was already aware of the difficulties in the graphic representation of multidimensional data (ibid.). It is in his spirit that the methods outlined below are used.

At the outset of this section, it should be stated that with ordination a one hundred percent representation is neither the norm nor should it be expected or aimed for. GAUCH (1982) expressed that the purpose of ordination is to filter a signal from noise. This result, of course, will not be achieved when the ordination computed represent, 100% of the variation (IBID.). When processing data sets with approximately 20 or more species, 30-50 % of the variation is usually represented within the first two axes (MCCUNE & GRACE, 2002).

When it comes to interpretation of correlations of possible environmental gradients and ordination axes in a Euclidean or at least linear reference frame, the expectations towards high linear relations have to be lowered right away. Instead of linear relations, unimodal responses may be seen far more often. Moreover, in nature, none of the factors act on their own and sometimes may integrate others as well. Since there are always interactions between environmental variables, a sole impact factor is not to be expected. Thus, very large impacts of only one variable should be the exception rather than the norm. Hence, the r values might be rather small. Again, albeit it being somewhat different in geography and chemistry, relations are seldom linear in nature. Moreover, the heterogeneity of the data set precludes high correlations and, as with ordination before, a high explained variance does not accomplish much since it does not separate the noise from a signal (MCCUNE & GRACE, 2002).

The above reasoning leads to the adoption of the following convention for the work at hand. Adhering to COHEN (1988, pp. 79ff), a correlation is considered small when $r = 0.10$, a medium correlation is inferable starting from $r = 0.30$ and a large one could be presumed from $r = 0.50$.

Although the correlation coefficients only represent the linear relationships of the variables with the axis, it is possible to detect "hump-shaped" responses as well. From overlays of the respective variables, these patterns are visible, albeit they may be obscured by a correlation coefficient which expresses only the linear part of the relationship (MCCUNE & GRACE, 2002). In other words, non-linear relationships will be misrepresented by correlation coefficients. Additionally, the correlation coefficients are valuable for descriptive purposes only. The computation of a significance value of the null hypothesis of no relationship would be ill-advised. The reason is founded in the fact that the ordination scores are not independent of each other, which would be one of the prerequisites for obtaining valid p-values (IBID.). The same authors (IBID.) stated that, besides that, sample sizes are mostly large enough that even small correlation coefficients are statistically significant. Thus, the researcher is encouraged to decide how small the effect size to be interpreted should be. Besides that, interpretation only allows for inferences rather than for discovering causal relationships. Moreover, what is sought is not an impact variable determining vegetation composition; it is instead a description of a possible environmental condition. No numerical method can extract such a condition in a definitive manner. Some truth is an all results.

Another point to be mentioned stems from the possibility that some of the variables may have extreme values and hence an unduly impact. Hence, very high r^2 values may result if the correlations in the data are dominated by a few outliers. In case outliers are present, or at least some samples with extreme values in some variables, CANOCO 5 offers the option to downweight these cases. The weights are chosen arbitrarily, thus some experimentation is needed. In the end, supposed outliers can of course be removed from analysis. Since the removal of samples always results in a loss of information, the measure will be used with caution.

A phenomenon that often occurs in the graphical results of ordination is a horseshoe or an arch in the depiction of the sample points. As PODANI & MIKLÓS (2002) pointed out, a horseshoe effect is indeed a mathematical necessity if the underlying gradient is unimodal. All of the diversity coefficients tested in their study proved to be confined to this effect except for the chi^2 metric and their own new coefficient. For linear data, the recovery rate of the Bray-Curtis coefficient was likewise poor with one exemption (ibid.). For high species turnover, they demonstrated a transition towards a circle. Even more so, it might not just be a unimodal response underlying the horseshoe, it might also be a change in species richness being represented here or both phenomena at the same time. The possibility of true artefacts has been avoided by performing the transformation as suggested by Gower (1966) and Legendre & Legendre (2012) and implemented by PC-Ord (McCune & M. J. Mefford, 2018).

The authors stated (ibid.) that, in order to distinguish between a species richness gradient and a unimodal response, it might be possible to compare ordinations based on Euclidean distance and the Manhattan metric. Without a change in species richness, both should give the same results indicating a unimodal response. In the case of a species richness gradient, both methods produce different results, i.e., an arch is obtained by ordination based on Euclidean distance and a straight line across the ordination space is produced by the Manhattan metric. Podani & Miklós (2002), following Kendall (1971), also found that when the relationship is a parabola, then the ordination will reproduce an entirely linear arrangement with Manhattan distance.

2.6.1 Unconstrained Ordination

To find a configuration of the samples in ordination space that reflects the differences in their species composition, unconstrained ordination techniques can be applied. The objective of an ordination is to project the relationships between species in multidimensional space into a space with a reduced number of dimensions, while keeping distortions of the spatial relationships minimal (see Šmilauer & Lepš, 2014). Two methods with different properties were employed to find the ordination axes that best predict the species configuration.

2.6.1.1 Polar Ordination or Bray-Curtis Ordination

Bray & Curtis (1957) were in search of an ordination method which would not impose some distance measure inherent to the method on the data to be analysed; in particular they sought the recovery of ecological gradients not depending on linear relationships. The original method quickly fell into disrepute since the choice of axis-endpoints by maximum distance emphasised outlier and, thus, complicated interpretation. Since the method does not rely on eigenvector analyses, the claim of a lack of mathematical rigour was raised. A comprehensive discussion on the issue can be taken from Beals (1984). In the work at hand, the advantages of the method will be used along with some improvements suggested by Beals (1984) and implemented to PC-Ord (McCune & M. J. Mefford, 2018). The first improvement pertains to the choice of endpoints. McCune & M. J. Mefford (2018) realised the option of selecting endpoints by variance regression. Due to the use of the variances in the distances among points, outliers will not determine the outcome since the distances to other points will generally be high, thus the variance will be lower (McCune & Grace, 2002). The first endpoint of an axis is the one with the highest overall variances in distances to all other points. The second endpoint is chosen in comparison to all other samples by regressions against their respective distance variances. The point with the least regression value (i.e., the most negative) will be the second endpoint of that axis and will be found at the other end of the longest axis. Through this method, no arbitrary definition of what constitutes an outlier is necessary, and removal is not needed. As a result, a cluster with complex shapes may also be analysed (Beals, 1984). Another advantage is the option of choosing endpoints manually. If prior information is available on possible underlying gradients, the samples at the opposite ends of the alleged gradient can be chosen accordingly. Furthermore, PC-Ord offers the option to apply any categorical variable as a grouping variable. Using this flexibility, the available qualitative variables have been tested for their effects. The possible lack of orthogonality of the axes (i.e., independence from each other), as derived by Bray-Curtis Ordination, is corrected for in PC-Ord. According to Leyer & Wesche (2008), the first axes may not necessarily be of descending importance; however, this seems to be more of a slight nuisance than an actual problem.

2.6.1.2 Principal Coordinates Analysis

In 1966, Gower devised this method to fully represent even non-Euclidean distance coefficients in a Cartesian coordinate system. The procedure embedded in PC-Ord follows Gower (1966) and Legendre & Legendre (1998). After the calculation of the distance matrix from the community table, the matrix is transformed by ahi = - ½D^2_{hi} in order to preserve the distance chosen in Euclidean space. Following this, the new matrix is centred by the subtraction of the respective row and column totals and by adding the grand mean of the matrix to each element. Thus, the distances between objects remain unchanged, but the origin of the new axes is in the centroid of the point scatter. From there, the eigenvalues and eigenvectors are calculated. With the semimetric properties of the Bray-Curtis index (i.e., the triangle inequality does not hold), some negative eigenvalues are expected to be created. Several corrections for the problem of negative eigenvalues and, thus, interpretation have been proposed (Legendre & Legendre, 2012). Since in the following analysis step the eigenvectors are scaled to $\sqrt{\lambda_k}$, the axes would be complex, i.e., not real. Cailliez & Pagès (1976, as cited in Legendre & Legendre, 2012) elaborated on the option that a representation derived as such is meaningful if the largest negative eigenvalue has an absolute value smaller than the m positive eigenvalues of interest. When calculating the R^2-like ratio for the quality of the representation in Euclidean space, the authors (ibid.) corrected the formula by adding a constant to both terms of the formula, achieving the same results as by correcting the distance matrix to attain metric distances and subsequently recomputing the PCoA (see Legendre & Legendre, 2012). The eigenvectors are then scaled to lengths equal to the square roots of their eigenvalues. The so-scaled eigenvectors, when written in columns, provide the table of the object coordinates in the space of the principal coordinates. In the last step, the eigenvectors are written into a table, and from the rows the coordinates of the samples in the PCoA space can be taken.

2.6.2 Constrained Ordination

In order to obtain more precise and directly quantifiable correlations among species data and environmental variables, constrained ordinations were carreid out. Two methods were utilized to obtain comprehensive analyses. Canonical Correspondence Analysis (CCA) was used to represent the unimodal fractions of variation. Redundancy Analysis (RDA) should usually not be applied to compositional data. Here two variants of the method were employed: transformation based RDA (tb-RDA) and distance based RDA (db-RDA). The ordinations have been carried out in the CANOCO 5 software (ter Braak & Šmilauer, 2012).

2.6.2.1 Canonical Correspondence Analysis

The ordination using CCA–Canonical Correspondence Analysis–is well known. The underlying preserved distance, the χ^2 distance, is apt to detect unimodal responses in the data. The characteristic of most species to show an optimum in abundance under certain environmental conditions and thus an unimodal response, is a regular natural occurrence. Hence, the choice of the ordination method.

In reference to CANOCO 5 (TER BRAAK & ŠMILAUER, 2012), it needs to be mentioned that the software treats the levels of categorical variables as single, i.e., as variables of their own. Thus, the symbols of the states of the respective categorical variable are placed at the centroids of the scores for the cases that have the particular factor level. In order to approximate the relative sum (sum of relative abundances) of responses (species) in the cases belonging to the considered class, the distance between the centroids of factor variables and response points can be used. Thus, the placement of the single factor levels is put in relation to all other variables within the diagrams. Thus, the position of a factor level in a diagram represents the weight mean of that level in respect to all other explanatory variables and in respect to the centroid of the respective categorical variable itself.

While CCA focuses on species composition, the chi-square distance preserved offers some disadvantages. When it comes to the interpretation of diagrams, the distance between sample points only approximates the chi-square distance when the axes explain a similar amount of variation (ŠMILAUER & LEPŠ, 2014). With the dissimilarity based on the chi-square distance any two samples with equal relative values are considered identical (IBID.). The behaviour of a CCA model depends on the relationship between the ecological distance and the chi-square distance. When beta-diversity is higher, FAITH ET AL. (1987) found the distance to perform poorly in this respect and deemed it one of the worst distances to analyse species compositional data. Though the weighting process contributes to the exclusion of double zeros, the weighting by species abundance (column sums) and frequencies (row sums) gives high weights to the richest sites. Additionally, if only a part of the range of a species is covered, the estimate is shifted towards the tail which is not truncated (ŠMILAUER & LEPŠ, 2014). Thus, if not all species distributions recorded cover the whole gradient, many of the species distributions will be truncated, i.e., the optimum estimates will be biased (IBID.). The longer the gradient the more species will have their optima estimated well (ŠMILAUER & LEPŠ, 2014).

2.6.2.2 Redundancy Analysis

The linear background of Redundancy Analysis (RDA) is well known. In principle multiple regressions are conducted for every environmental variable and every species, finding the least squares deviation from the mean. The fitted values (to the regression line) are then used in a constrained PCA. Thus, the canonical ordination vectors are linear combinations of the response variables which are also constrained to be linear combinations of the explanatory variables. In difference to the unimodal model above, the simple multiple regressions are done on the raw species composition data. Thus, the responses are not based on the weighted average of all species in each sample, i.e., samples are not weighted by species abundances. Since linear correlations are rather rare in nature, a linear model is not well suited to represent species responses along a (long) gradient.

This shortcoming can be ameliorated by the prior transformation of the data in a way that the abundance values are first divided by the site total abundance, and by taking the square root subsequently. Hence, only species relative abundances are considered for a site. If data thusly transformed are used in RDA, i.e., the Euclidean distance is calculated between the data points, the Hellinger distance is preserved during the analysis (LEGENDRE & GALLAGHER, 2001). This distance is then not impacted by the double zero problem while it still keeps the metric properties. While losing the impact of single species abundances, the focus is shifted to compositional changes and the robustness of the linear method is increased (Šmilauer & Lepš, 2014).

While LEGENDRE & GALLAGHER showed in their 2001 paper that a Hellinger-based data transformation allows the use of RDA in the present context, MINCHIN & RENNIE (2010) found that tb-PCA had been unable to recover the simulated gradients in their experimental approach. Additionally, ŠMILAUER & LEPŠ (2014) state the procedure may not be the best choice for highly heterogenous data.

Despite using the transformed species data to assess compositional changes, RDA can also be utilised in a distance-based form (LEGENDRE & ANDERSON, 1999). Here, almost any distance measure can be applied to describe the relations between community composition and explanatory variables.

Instead of being based on PCA, the RDA conducted is based on PCoA. Thus, it presents a constrained form of Principal Coordinates Analysis. In order to execute the analysis, first a dissimilarity matrix among the cases must be computed. Here, applying the appropriate transformation, most distance measures are eligible. The resulting principal coordinates are then used in a consecutive RDA. In such a way, the effects of environmental factors upon responses (in the form of samples) can be tested. As with the methodes before, covariates can be used which then makes partial techniques possible (ŠMILAUER & LEPŠ, 2014). Since the distances between cases are modelled, the relation between species and the constrained axes are lost. For the same reason of course variation partitioning procedures cannot be used based und db-RDA.

2.6.2.3 Hierarchical Approach

Canoco 5 offers the option to analyse community variation in a hierarchical manner. For the data at hand, there are three level to be considered: the forest identity, the position towards the watershed, and the variation between the ranger stations. Canoco 5 allows for the aggregation of samples for instance at the level of the ranger station to only express the variation present between the respective stations. The permutation procedures are adapted accordingly, i.e., the samples are not permuted between the different aggregated units. The conditions of the survey area did not allow for the application of the hierarchical procedure in all of the cases. For two of the forests there is only one ranger station, and both of the forests are entirely on the Congo side of the watershed. Hence, a valid and reliable statistical test would not be possible. Therefore, the hierarchical scheme could only be applied in its intended form to Nyungwe Forest alone. Here, the variation among the ranger stations and the variation in species data due to the position towards the watershed were analysed by aggregating and permuting the samples in constrained ordination analyses at the respective level (ranger station and watershed position). An exhaustive overview of the procedure can be taken from ŠMILAUER & LEPŠ (2014).

2.6.2.3 Partial Methods

Both of the afore mentioned methods are amenable to partial procedures. In the real world, an effect on a response variable (species) is seldom carried out by only one impact variable. Even more impact factors might be correlated. Using partial regressions is a way of elucidating the sole impact of an environmental factor. It can thus be explained how much of an exclusive impact a variable has once the effect of the other has been accounted and controlled for (Legendre & Legendre, 2012). This also opens the option to estimate the joint impact of the explanatory variables. Basically, the regressions are computed sequentially. In a first regression, the effect of one impact factor is calculated, while the second regression is calculated on the residuals of the first one.

In RDA, the regressions are conducted in very much the same way since RDA is the extension to multivariate data. First response matrix Y is regressed on W (the matrix of Covariables) and X (the matrix of explanatory variables) is regressed on W. From here the residuals of Y can be regressed on the residuals of X. The R^2 resulting from this approach, is the partial canonical form.

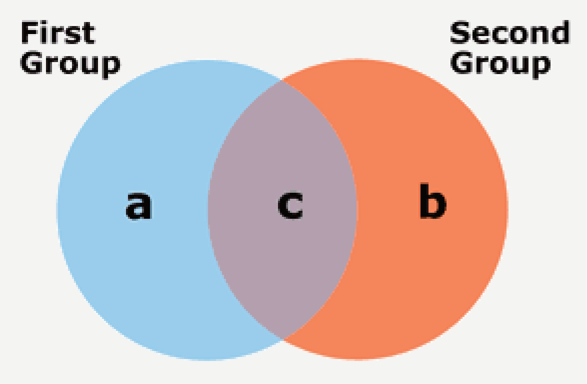

Figure 2.3: The fractions resulting form variation partitioning with two groups of explanatory variables. The grey rectangle represents the variation that remains unexplained. Fraction c must not be interpreted as an interaction term. It represents the correlation between the two groups of explanatory variables.

From this approach, variation partitioning can directly be derived. Aim of the method is to subdivide the variation of community composition data among the impact of two or more collections of explanatory variables. The method was developed by Borcard, Legendre, & Drapeau (1992). The grey rectangle represents the whole variation in the community data. Parts a,b and c represent the variance explained by the respective groups of impact variables. Part c however must not be mistaken for an interaction between the two groups of variables. It merely represents the correlation among the two groups of variables. Fraction a represents the partial effect of the variables in this group. Ignoring the variables in group b, the amount of variation explained by just a would be measured by a+c. The same holds true for fraction b. When using covariates in the analyses, first the variables from group a are used in a partial analysis where the variables from a act as explanatory and the variables from part b take the role of covariables. The same is done with group b. The amount of c is then calculated as subtraction of the combined partial results (a+b) from the variation explained obtained by a constrained analysis using both a and b as explanatory variables. Alternatively, the variation explained by a complete constrained analysis (a + b + c) can be compared to the results from analyses using either a or b as explanatory variables, i.e., comprising a+c or b+c.

The variables contained in group a and b can be selected a priori e.g., based on preceding analyses or the can be chosen by interactive forward selection as also offered by Canoco 5. These options can be used to make the groups as similar as possible in size. The importance is given by the fact that the amount of variation explained might grow with group size even if none of the additional variables has a real effect (Šmilauer & Lepš, 2014, pp. 89-90).

2.7 Spatially explicit Methods

It has been stated before that space, i.e., the distance between samples can be used to reveal at which scales community composition varies and what patterns arise at these scales. The variation in the response data could thus be related to explanatory variables which may act at different scales. Moreover, beta diversity, the spatial variation in community composition among sites, may be related to different environmental factors at different scales. A question that might be answered here is the one about the separation of environmental control and neutral processes.

It must not be forgotten however that of course space itself as an explanatory variable is a mere proxy for real environmental or ecological explanatory variables. With the spatial predictors calculated the spatial variation of the community data can be quantified and divided. Some fractions of the variation can then be related to some of the explanatory variables and some of the variation remains unexplained. Another occurrence, though spurious, could be the correlation between environmental factors and community data based on independently caused spatial variation in both (Šmilauer & Lepš, 2014).

2.7.1 Trend-Surface Analysis

A basic form of analysing spatial structures in the response data is to create spatial descriptors based on the geographic coordinates of the sample sites. The aim is to express a response variable as a non-linear function of the geographic coordinates of the sampling sites were the variable was observed (Legendre & Legendre, 2012, p. 822). Surfaces can be modelled by using extensions of the coordinates in the form of power terms. These terms are called trend-surface polynomials (Legendre & Legendre, 2010, pp. 877-881). In this case a (polynomial) regression model is used to compute the estimates of a variable at a given location.

With trend-surfaces, gross spatial structures can be detected showing broad scale changes in the responses across the whole of the study area. Those far-reaching trends can be detected only in the form of monotonous changes or smooth non-linear changes (Šmilauer & Lepš, 2014). Smaller scale patchiness or other types of spatial heterogeneity patterns or a characterisation and comparison of spatial heterogeneity occurring at multiple spatial scales cannot be detailed. Another drawback is the inflated Type I error in the method if the correlation between space and environmental factors is indirect (Peres-Neto & Legendre, 2010).

Using the appropriate order of the trend surface equation, the method can be used to compute the residuals from a trend surface equation i.e., to detrend a variable (Legendre & Legendre, 2012, p. 825). This can be desirable if the broad scale is already known and interest lies with finer and localised spatial structures. Hence, the broad scale trend has to be removed.

2.7.2 Distance-Based Moran's Eigenvector Maps

The finer spatial scales are modelled best by what is known as spatial eigenfunctions. These can be deployed as independent variables in e. g. variation partitioning. The method uses a matrix of spatial predictors that are mutually orthogonal to each other. This entails that the linear independence allows sub models corresponding to different scales to be computed without overlap. Thus, they would also be linearly independent of one another in variation partitioning. The method was originally described by BORCARD & LEGENDRE (2002), BORCARD, LEGENDRE, AVOIS-JACQUET, & TUOMISTO, 2004) and LEGENDRE & BORCARD (2006, as cited in LEGENDRE & LEGENDRE, 2012).

In a first step, the geographical coordinates are used to compute a Euclidean distance matrix among all sampling plots. This distance matrix is then truncated at a distance beyond which all distances are set to large. After this, the matirx is subjected to a PCoA. The eigenvectors and eigenvalues different from 0 thus computed contain the distance relationships among sites at all scales. The positive eigenvalues model positive spatial correlation while the negative eigenvalues model negative correlations. The axes obtained by PCoA reflect different spatial scales. The first axes represent coarse scales. With increasing axis number, the scales become gradually finer. Thus, the spatial predictors can be divided by the scale of the spatial variation they reflect. The eigenfunctions computed from the spatial distance matrix are called Moran's eigenvector maps.[3] In this case, since they are based on simple geographic distances, they are called distance-based MEM.

Before the variation can be partitioned, a separate constrained ordination to select the spatial predictors that are important for the response data has to be run. After this procedure, variation partitioning can be applied to distinguish spatially structured environmental effects from environmental effects unrelated to space. However, the recovery of the origin of the correlation, i.e., the establishment of a causation, is rather illusive. Therefore, the interpretation of the spatially structured environmental effects can proceed under two paradigms. Assumption number one: the correlation is indirect; community composition and environment are both impacted by external factors. Presumption number two: the correlation is direct; the environmental variation is spatially heterogenous on its own (LEGENDRE & LEGENDRE, 2012, pp. 878-881; see ŠMILAUER & LEPŠ, 2014).

LEGENDRE & LEGENDRE (2012) recommend that, if a linear gradient is present in any geographic dimension in the response data, such a gradient should be removed. Certainly, the dbMEM are capable of modelling linear spatial gradients. This should be avoided though, for two reasons. The first rationale is that by using a large number of eigenfunctions to model a gradient which is only a part of a structure that is larger than the study area, nothing would be learned. Such a spatial structure can be modelled more simply by a linear function of the geographic coordinates of the sites on a surface (see above). Secondly, more interesting structures cannot be modelled, if the eigenfunctions are used to model gross linear trends (LEGENDRE & LEGENDRE, 2012, p. 868). Hence, the data should be detrended before further analyses.

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[3] The reason for the name is given in LEGENDRE & LEGENDRE (2012, p. 863). The paper of DRAY, LEGENDRE & PERES-NETO, 2006) gives a detailed theoretical background.

2.8 Adjustments for Significance and Explained Variation Percentages

ZAR (2011, citing EZEKIEL, 1930) offers a coefficient of multiple determination (R^2) which is corrected for by considering the appropriate number of degrees of freedom. Thus, R^2 is no longer biased by the number of independent variables and the samples size. In other words, R^2 may increase when an explanatory variable is added to the model, whereas R^2adj will only increase when the fit of the regression is improved by this variable (ZAR, 1999, p. 423). In this way, models with different numbers of independent variables and sample size can be compared (PERES-NETO, LEGENDRE, DRAY, & BORCARD, 2006). PERES-NETO ET AL. (2006) developed the adjustment further to accommodate data from canonical analysis based on centred values. For CCA the authors (IBID.) gave an option to adjust R^2 on the basis of a permutation procedure. The options referred to above are implemented into CANOCO 5 and were applied respectively.

The R^2_{adj} is not only used to measure the amount of variation explained, it is also used as a second stopping criterion in forward selection especially in dbMEM. BLANCHET, LEGENDRE & BORCARD, 2008), proposed to use this second stopping criterion in order to further reduce inflated Type I error. By using the R^2adj of the global model, tested on the response variables with 999 permutations, as a base line and then comparing the submodel R^2_{adj} to it during forward selection prevents the submodel to explain more of the variation than the model including all of the explanatory variables. This does not preclude the possibility though of finding a well-fitted model, but it may not be the best one for the given community data. In the simulations run by BLANCHET ET AL. (2008), the use of an adjusted R^2 and the use of the alpha level as stopping criteria, greatly reduced Type I error and lead to an additional selection of unimportant explanatory variables in under 1% of the tests. On the other hand, none of the important spatial predictors were prevented from entering the model (IBID.) The corrections presented above are available in the CANOCO 5 interactive forward selection procedure, and were used respectively.

2.8.1 False Discovery Rate

Another option to prevent an inflated Type I error is the correction of the significance level (p-values) in the case of multiple testing. The Bonferoni correction was deemed too conservative considering the data base, and the heterogeneity of the environment and the vegetation. Thus, the false discovery rate as offered by CANOCO 5 has been deployed. The false discovery rate in simultaneous testing is defined as the expected proportion of true null hypothesis rejected out of the total number of null hypothesis rejected (BENJAMINI & GAVRILOV, 2009). Here, the p-values are corrected by first ranking them from smallest to largest and then multiplying the set alpha level by the rank of the p-value divided by the overall number of tests (BENJAMINI & HOCHBERG, 1995). Thus, they represent not a probability of Type I error. What they estimate is a rate with which null hypotheses are rejected, in the case this, and all the better candidate terms, were selected (TER BRAAK & ŠMILAUER, 2012; TER BRAAK & ŠMILAUER, 1997-2019; BENJAMINI & HOCHBERG, 1995).

Although there are opinions according to which those adjustments may not be necessary in protected tests such as CANOCO 5 executes when using the interactive forward selection procedure (ŠMILAUER & LEPŠ, 2014, p. 91). Some authors argue that while decreasing the chance of Type I error the chance of Type II error is increased (FEISE, 2002). Thus, enhancing the chance to rule potentially valuable variables out. Throughout the study the 95% significance level is regarded as sufficiently powerful.

2.8.2 Variance Inflation Factors

The outcome of regression models depends as well on the correlation among the different explanatory variables. Multicollinearity, or near-linear dependence, can be expressed in the form of so-called variance inflation factors. The name derives from the inflation of the variances of the regression coefficients because of the multicollinearity (Montgomery & Peck, 2012). The VIFs can be calculated by regressing one of the explanatory variables against the remaining explanatory variables. The resulting R^2 is related to the VIF by VIF = $(1-R^2)-1$. Thus, if a nearly linear correlation is present, R^2 will be near unity and the variance inflation factor will be large (Montgomery & Peck, 1982). Ter Braak & Šmilauer (2012) state that a VIF larger than 20 is evidence of a variable almost perfectly correlated with the other variables and therefore has no unique contribution (ibid., p.176) It follows that the regression coefficient is unstable and should not be interpreted (ter Braak, 1986 as cited in ter Braak & Šmilauer, 2012, p. 176). The unstable results also bring about that any extrapolated prediction of response variables is likely to be poor (Montgomery & Peck, 1982). According to Borcard, Gillet, & Legendre (2018) VIFs above 10 should be examined and variables should be subjected to a selection procedure. In the Log pages provided by CANOCO 5 the respective variance inflation factors are given. If the option was given, variables exhibiting high VIFs were removed on the basis of the available selection procedure.

2.9 Rarefaction

Since the samples contained different numbers of species and more rare species only entered the species list with increasing sample number, the comparison and estimation of species richness among samples is biased (Borcard et al., 2018). In order to ameliorate this downward bias within the estimates of the true numbers of species (in the samples), a rarefaction procedure without replacement was carried out in order to assess the sampling effort and to extrapolate the number of species to be expected (Gotelli & Colwell, 2011 in: Magurran & McGill, 2011). The resampling process was carried out using sample-based procedures resulting in the expected number of species in the pooled samples following Colwell et al. (2012) as well as Chao (1984, 1987). Rarefactions were calculated by the EstimateS 9.1 software (Colwell, 2013).

2.10 Diversity measures

In the following, an overview of the diversity measures used is provided. Beta Diversity is considered as the variation in species composition among sites within a geographic area of interest throughout the study. Hence, it follows Whittaker's (1960) definition. Furthermore, beta diversity is defined as species variation among sampling units, notwithstanding any underlying environmental gradient. Alpha and beta components of diversity are considered independent of each other in the study. The diversity measures used have been calculated utilising the vegan package for the R software (Oksanen et al. 2018).

2.10.1 Percentage Difference or Bray-Curtis Index

Bray & Curtis (1957) used a similarity measure in their effort to develop an ordination method in order to display ecologically meaningful distances. They attributed said measure to Motyka, Dobrzanski, & Zawadzki (1950). According to Legendre & Legendre (1998) Odum

(1950) first described the measure in form of a dissimilarity and called it the percentage difference. Throughout the work at hand, the measure will be called BRAY-CURTIS index for ease of use. The various sources and names for the index and its development will not be discussed any further and are not subject to this survey.

2.10.2 Raup-Crick Index

In order to have a point of reference on where to globally cut the dendrogram derived by UPGMA without resorting to independent variables, a second fuzzy c-means clustering has been conducted on the basis of the RAUP-CRICK (RAUP & CRICK,1979) metric. Since the clustering algorithm was run on the basis of the plant communities devised before, sampling effort among the units is of course unequal. Hence, a probabilistic measure invariant to sample size was chosen. The metric can be used to obtain information on how much more different communities are than expected by chance alone (CHASE, KRAFT, SMITH, VELLEND & INOUYE, 2011). Using the metric as a dissimilarity, such dissimilarity is presented as the difference among two communities relative to the null expectation. Given a number of shared species between two sites with α_1 and α_2 species respectively, the randomisation approach is aimed at estimating the probability of observing a number of shared species larger than the given number. The algorithm is provided in detail by CHASE ET AL. (2011). A shortcoming of the index is the use of incidence data. In the current version of the vegan package for R the sampling probabilities can be adjusted for species frequencies (OKSANEN ET AL., 2018)

2.10.3 Numbers equivalents according to Jost

Another means of describing diversity are the so-called diversity-numbers (HILL, 1973), HILL numbers (BORCARD ET AL., 2018) or numbers equivalents (JOST, 2007). These numbers give the effective number of species present (HILL, 1973; see MACARTHUR, 1965). In other words: "The numbers equivalent of a diversity index is the number of equally likely elements needed to produce the given value of the diversity index" (JOST, 2007, p. 2428). Based on different measures, the order of the numbers equivalent gives the sensitivity of the measure to rare and common species. Pure species richness (order $q = 0$) is sensitive to rare species, order $q = 1$ following from SHANNON's measure is insensitive to rare or dominant occurrences and only takes species frequencies into account, the SIMPSON based numbers equivalent ($q=2$) is sensitive to common species. JOST (2007) used these numbers equivalents to partition species diversity into independent alpha, beta and gamma components. For true diversities sensu JOST (2007), beta ranges between 1 and N, and gives the effective number of completely distinct samples (JOST, CHAO & CHAZDON, 2011, p. 79 in: MAGURRAN & MCGILL, 2011). Thus, it measures the divergence between the species probability distributions of the assemblages (IBID.). Using transformations JOST (2007) likewise exemplified that true beta can be used to calculate species overlap between samples. Again, depending on the power of the basic sum, i.e., the order of the measure, the impact of rare and dominant species is represented (JOST, 2006, 2007). When $q = 0$ the SØRENSEN index is produced, when $q = 1$ the Horn index of overlap is calculated and $q = 2$ gives the MORISITA-HORN index (IBID.). The R package vegetarian was employed to calculate the Jost diversity measures for community data (CHARNEY & RECORD, 2015).

2.10.4 Beta Diversity from the Variation in Species Data and Local Contribution to Beta Divesity

In 2013 LEGENDRE & DE CÁCERES developed a method to compute total beta diversity from the variation in species data, Var(Y). Thereby, the total sum of squares in the species data is divided by (n-1). In order to compute BDTotal from SSTotal the data must be transformed prior either by Hellinger or chord transformation otherwise the Euclidean distance would be derived (BORCARD ET AL., 2018). LEGENDRE & FORTIN (2010) proofed that Var(Y) can directly be obtained from a dissimilarity matrix. Here, also the BRAY-CURTIS index is eligible. For dissimilarity indices ranging between 0 and 1 BDTotal can reach a maximum value of 0.5 for indices with a range of [0, √2] the maximum value is 1. This measure of beta diversity can be decomposed into the local contributions of the sites to beta diversity (LCBD). As expressed by LEGENDRE & DE CÁCERES (2013) the "*degree of uniqueness*" of species composition in the samples is described. The local contribution of the ith sample is described by LCBDi = SSi / SSTotal with SSTotal = $\sum^{n}_{(i=1)} ss_i$. The calculation of LCBD from a dissimilarity matrix necessitates the same transformations as given for PCoA above (LEGENDRE & DE CÁCERES, 2013). The derived values for the LCBD can be tested for significance by a permutation procedure, the p values obtained have to be corrected for multiple testing. Here, the Holm procedure as applied by LEGENDRE & DE CÁCERES (2013) and embedded in adespatial is used. The sites attained by the afore procedure can contribute to beta diversity by any divergence from the overall species distribution pattern. The package adespatial for the R software was used to conduct the computations (DRAY ET AL., 2019).

2.11 Mantel Correlogram

Multivariate spatial correlations can be described by means of a Mantel correlogram (SOKAL, 1986; ODEN & SOKAL, 1986). In general, a correlogram depicts the spatial correlation values in respect to geographic distances (LEGENDRE & LEGENDRE, 2012). Since the focus is on species composition, the multivariate means is used to illustrate the omnidirectional correlations among sample sites. Although an underlying structure can be detected, the information provided is not specific (IBID., p. 800). The principle calculation is detailed in LEGENDRE & LEGENDRE (2012, p. 819). The breakpoints for the distance classes were chosen using the rule of STURGES (1926) in order to reach an objective conclusion on the decision between the resolution of the correlogram and the power of the test (LEGENDRE & LEGENDRE, 2012). Since multiple tests are performed simultaneously during calculations, the increased chance of type I error had to be countered. Here, the HOLM (1979) correction, as recommended by Borcard et al. (2018), was applied. Less conservative than the BONFERRONI correction ($\alpha' = \alpha/k$) (1935), the uncorrected p-values are divided by k in increasing order, i.e., sequentially by lowering the correction value (e.g., k-2, k-3, …) until a non-significant p-value results. The function to calculate the correlogram is provided in the package vegan for the R software (OKSANEN ET AL., 2018).

3 Classification and General Results

The subsequent paragraphs will serve to present the results. We will begin with the presentation of the general results, followed by the display of the beta diversity in its numerical form. The outcomes of the classification approaches are given subsequently. This is succeeded by the results of the indirect ordinations, which are followed by the direct ordinations results. The latter were also carried out in their partial form, the results of which are presented below. The spatial analyses and partitioning approaches form the conclusion of the ordinations.

3.1 General Results

During data collection, 1198 species in 127 families have been encountered. Of these species, 505 could be determined to species and subspecies level, 487 of which without a doubt. Further 498 species could be identified to the level of genera. Altogether, 176 species could not be identified without uncertainty and a 195 species were only distinguished as morphospecies. Of all the species encountered, 6 are local endemics and 40 are Albertine Rift endemics. In total, 816 species occurred only once in the sample data.

Of the 505 reliably determined species, information on distribution among the phytochoria could be retrieved for 391. Of those, only 40 are restricted to only one of the phytochoria described by WHITE (1983). With 36 species, these are predominantly restricted to the afromontane regional centre of endemism. Overall, the species evaluated can be present in 18 phytochoria, namely the: Afromontane, Afroalpine, Lake Victoria Regional Mosaic, Sahel Regional Transition Zone, Sahara Regional Transition, Sudanien Region, Guineo-Congolian-Sudania Regional Transition Zone, Guineo-Congolian, Guineo-Congolian-Zambezian Regional Transition Zone, Guineo-Congolian / Zambezia Transition Zone, Zambezian Region, Kalahari-Highveld Regional Transition Zone, Cape Region, Tongaland-Pondoland Regional Mosaic, Somalia-Masai Region, Zanzibar-Inhambane Regional Mosaic, East Malagasy Region and West Malagasy Region.

The species-area relation can be taken from Figure 3.2. While within some of the sample sites the increase in species number is moderate, the over-all slope is rather steep and an overall plateau is not attained. In order to give an estimate of species numbers present in the survey area, rarefaction methods were employed. The sample-based rarefaction resulted in estimated 2791 possible species while the Chao1 measure gave 2828 species to be expected (Fig. 3.1).

Since every study aiming to explain the spatial variation of community composition is an analysis of beta diversity, the task that one has set out to solve could be considered accomplished by focussing only on the ordination procedures. Yet, the term beta-diversity is always connected to some specific numbers in ones mind. Hence, a parsimonious numerical expression of Beta-Diversity will be given in the following. When it comes to species diversity, it is a well-known postulate that dissimilarity increases with distance. A diastemogram was created to illustrate this connection (LEGENDRE & GALLAGHER, 2001) (Fig. 3.3). The graph shows a rapid increase in dissimilarity within the first seven km. While the dissimilarity remains at a high level over the entire distance, increased similarities between samples at a greater distance to each other can be observed in some distance classes. The r^2 value of 0.15 for the relationship between distance and dissimilarity reflects a less pronounced relationship. This notion can already be derived from the average pairwise percentage difference widely known as Bray-Curtis dissimilarity of 0.92. Another means to express beta diversity by a single number is the total variance in Y, i.e., in species data. Here total beta diversity amounts to $BD_{Total} = 0.43$ based on Bray-Curtis dissimilarity. Based on Hellinger transformed data $BD_{Total} = 0.87$. For both diversity measures, the LCBD after Holm correction remained significant for samples sites 10_{NU}, 48_{C}, 56_{C}, 57_{C} and 60_{C}. Sample 10_{NU} was placed in an open and treeless formation. The reason why the vegetation on site merely consisted of herbal species is not clear. A fire in the past seems the most likely option since from satellite images no clear indications of a land slide were visible. The remaining four samples all came from Cyamudongo Forest. Beyond this commonality, three of the samples show elevated values for [Ca]:[Al] and for [Mg]:[Al]. Here, sample 48_{C} shows no elevated values compared to the mean. This sample is located in the direct vicinity of the forest edge at a *Eucalyptus* plantation. The species composition of the samples is discussed in the chapters on classification (see 3.2).

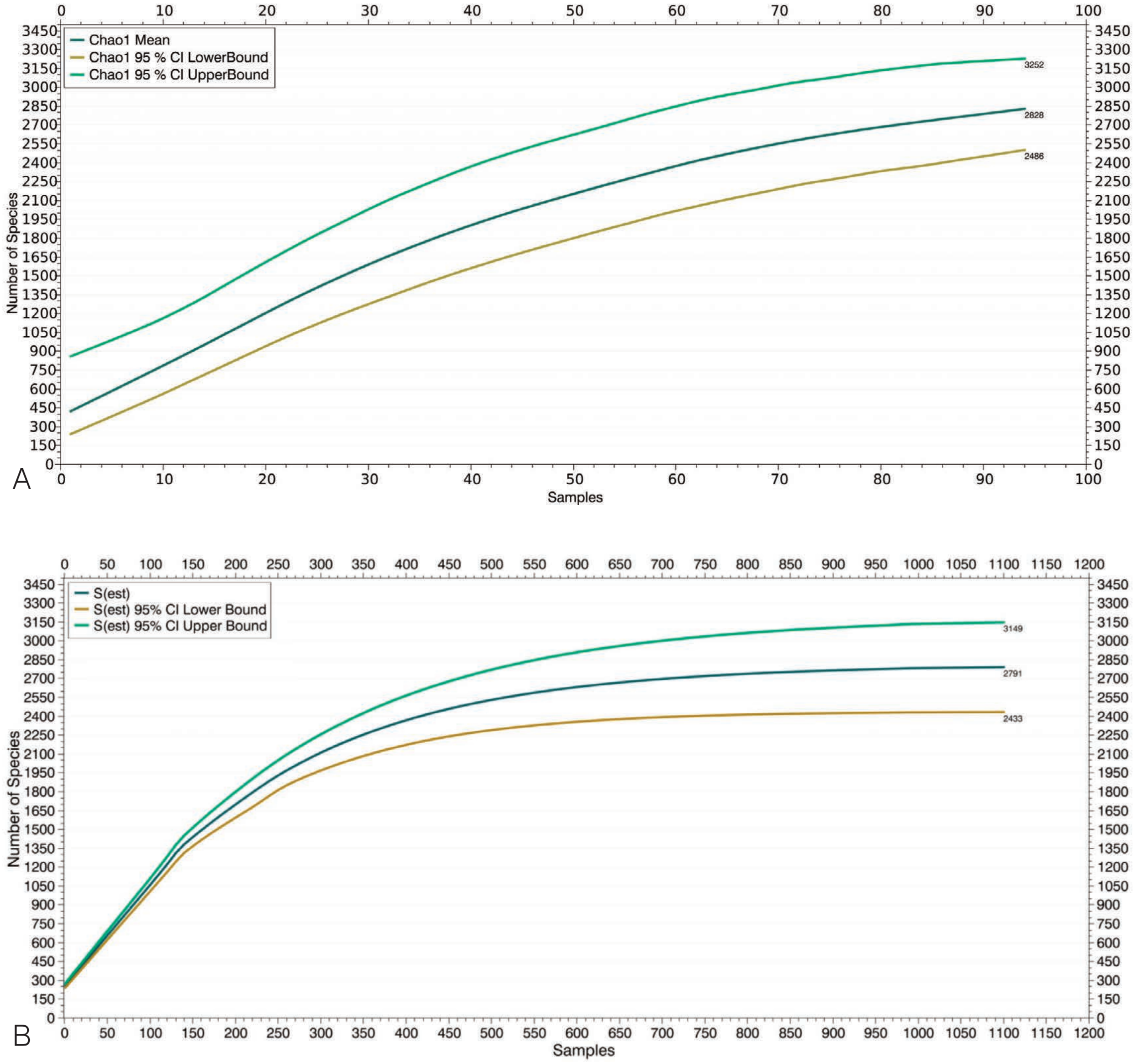

Figure 3.1: Rarefaction curves as computed using the Chao1 measure (Chao, 1984) (pane A) and the sample based measure by Colwell et al. (2004) (pane B).

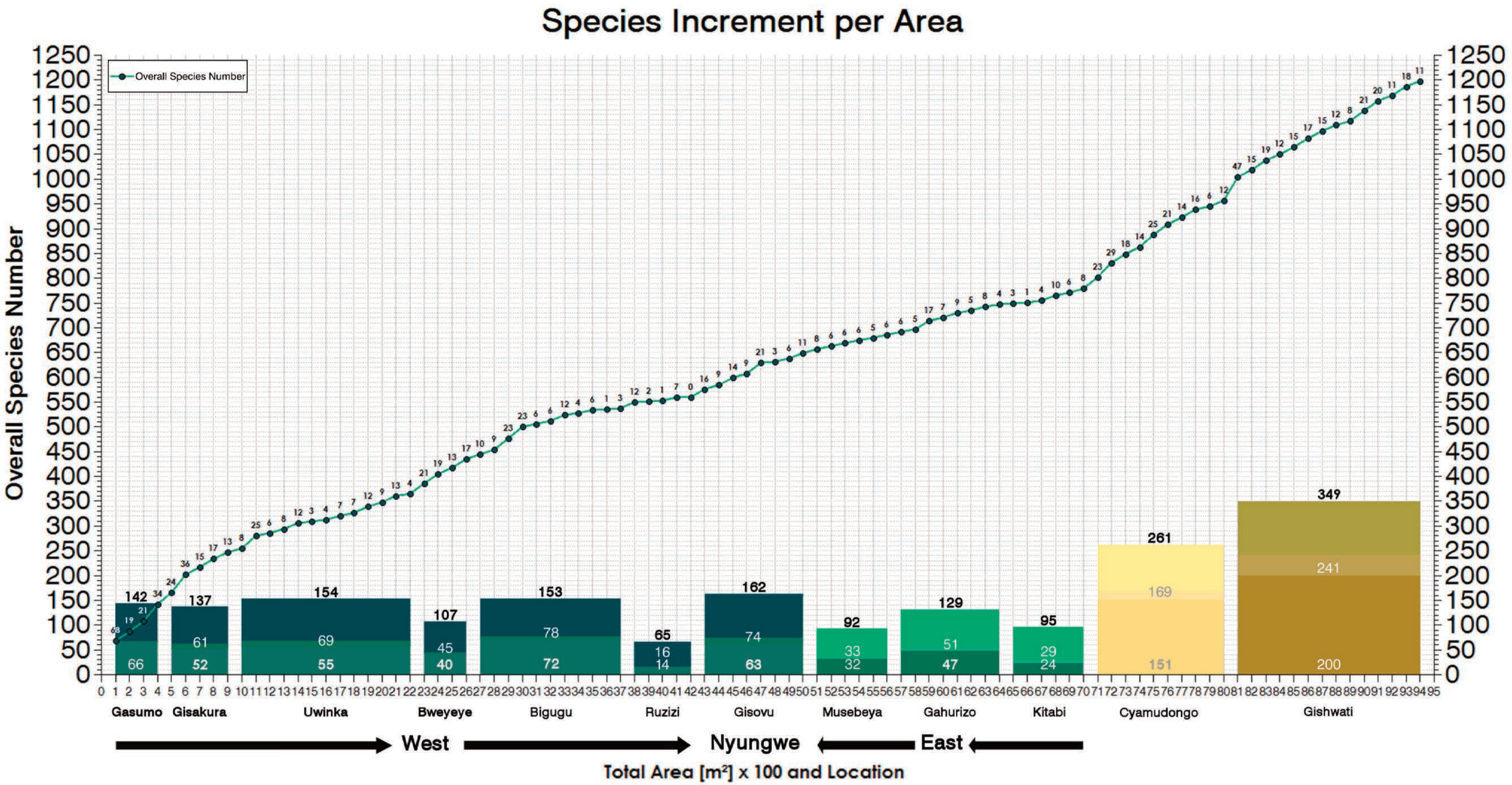

Figure 3.2: Species increment per sample site and ranger post. The numbers above the dots of the graph give the additional species per sample. The bars representing the ranger posts are three-part, the number at the top is the total number of species encountered at the respective site, the second number represents the number of species only occurring in the vicinity of the respective ranger post, the number at the bottom represents the species only occurring once in the survey.

In order to give some more detail in terms of diversity, the method developed by JOST (2007) was applied. The partitioning of diversity into independent α, β and γ components resulted in a Shannon based alpha diversity of a necessary 8 species per sample in order to gain the diversity of the sampled set. This number equivalent accounts for the diversity of a sample considering all species equally abundant. Taking the diversity level to beta, the Shannon based numbers equivalent gave a result of 15.37 equally likely elements needed, in this case samples, to result in the given diversity (JOST, 2007, p. 2438). Since species count per sample differs, i.e., the weights of the samples differ in the sense of JOST (2007) only the Shannon based measure is valid when considering further analyses. As sample size is not of importance, we take a look at the numbers equivalent of order 0 which is sensitive to rare species. The numbers equivalent results in 37.90 equally likely elements needed to represent the diversity present in the actual sampling population. Gamma species richness is of course 1198 based on species numbers and based on SHANNON diversity 123.39 equally distributed species would be needed to obtain the diversity observed within the samples.

Before we turn to the analyses of the vegetation data to elucidate if any compositional patterns are present, we will determine if a spatial correlation in the species data is present. Since we are bound on discovering compositional structures and drivers of possible differences in species composition, we will follow a multivariate approach to spatial correlation. Here, we will use the Mantel correlogram as detailed under 2.11.

As can be seen from figures 3.5 and 3.6, there are no significant correlations to be found in the data from Cyamudongo and Gishwati Forests. Hence, no possible zone of influence of the stands represented by the sample sites can be delineated. The samples from Nyungwe Forest on the other hand reveal positive spatial correlation in the first distance class. The second and third distance class as well as the fifth and sixth distance class exhibit negative spatial correlation. The first distance class ranges from 0.016 to 3.42 km (see break points) and hence gives an average zone of influence of the vegetation found in the respective sample sites. While for Gishwati and Cyamudongo the implication of no spatial correlation has to relativised because of the low n and thus test power, it has to be maintained that the result for Nyungwe Forest is an average for all types of vegetation and should not be generalised. Here, a more detailed approach in terms of resolution and geographical direction his hampered due to the loss of test power resulting from low n in the respective distance classes.

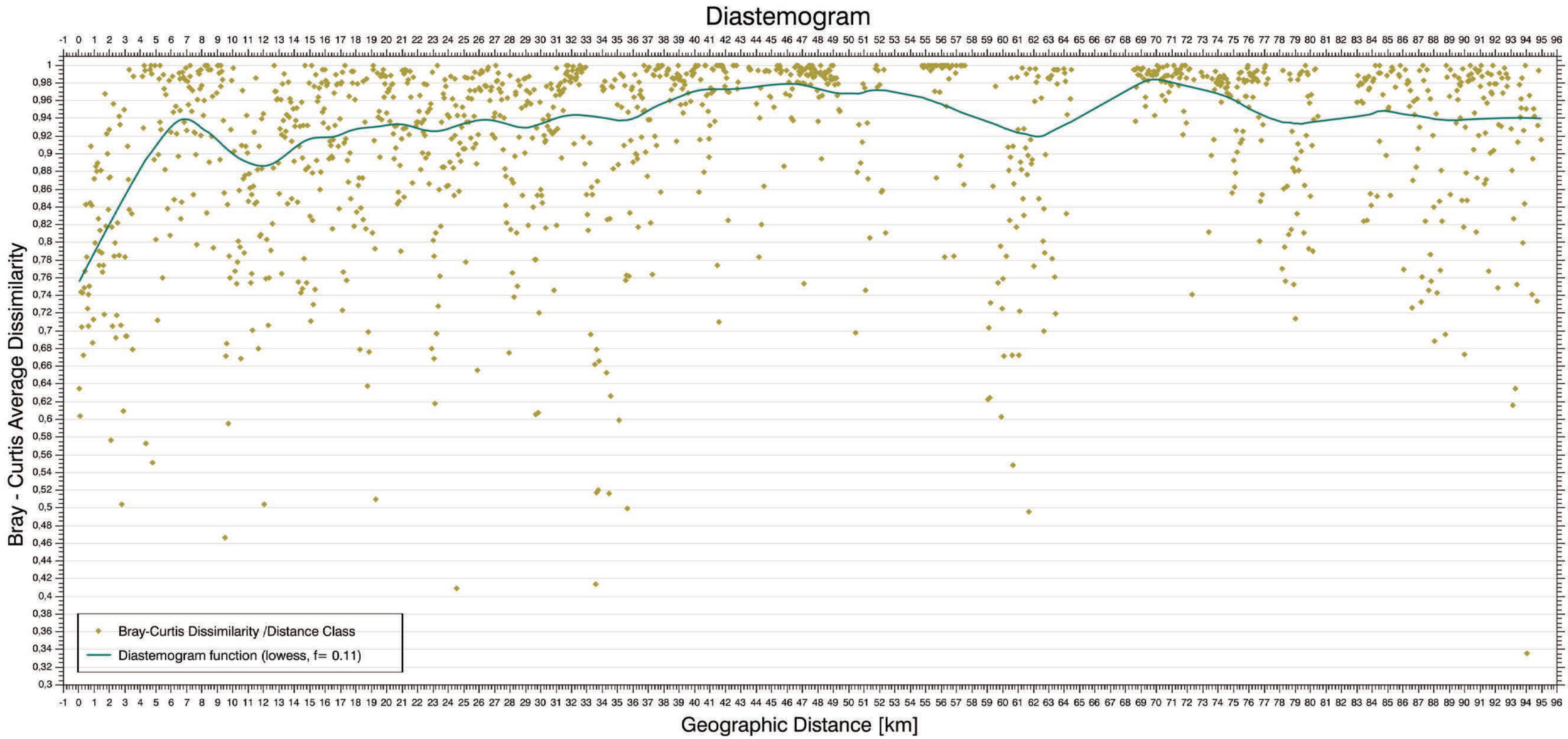

Figure 3.3: Change in the average BRAY-CURTIS dissimilarity values per 50 m increment.The correlation between the average values and the lowess smoothed line is $r^2 = 0.15$. Although the increase of the dissimilarity in the first few distance classes is rather steep, the average dissimilarity is high from the beginning. The general assumption that dissimilarity increases with distance can only be confirmed to a limited extent. As can be seen in the higher distance classes, some values are clearly below the average. However, an exchange between these areas does not seem to be possible.

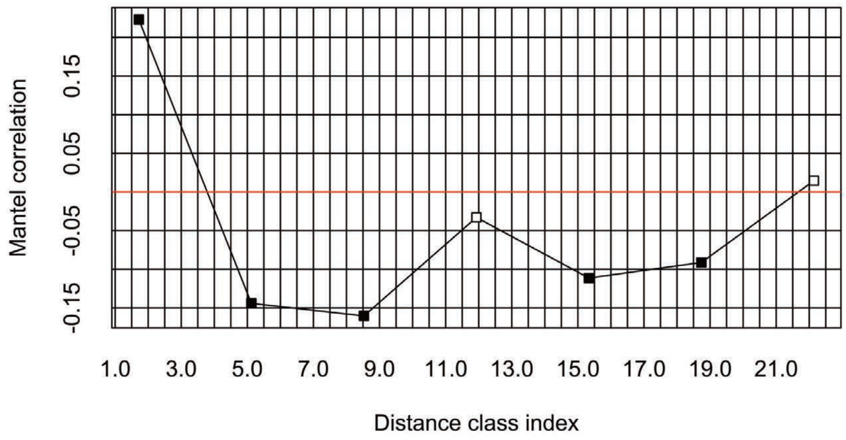

Figure 3.4: Mantel correlogram of the samples from Nyungwe Forest. Black squares indicate significant correlations at the 0.05 alpha level after Holm correction.

Break Points Forests	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Nyungwe	0.016	3.420	6.824	10.228	13.632	17.036	20.440	23.844	27.248	30.652	34.056	37.459	40.863	44.267
Cyamudongo	0.109	0.464	0.818	1.172	1.527	1.881	2.235	2.590						
Gishwati	0.042	0.412	0.782	1.153	1.523	1.893	2.263	2.633	3.003					

Table 3.1: Breaking Points of the Mantel correlograms. The distances are given in km and have been rounded to three decimal places.

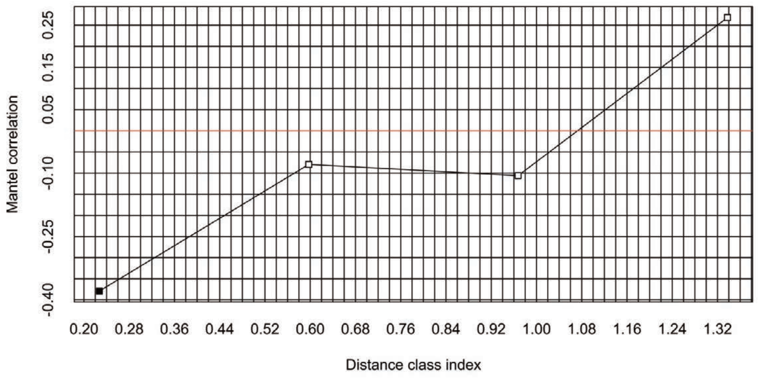

Figure 3.5: Mantel corelogram of the samples from Gishwati Forest. Black squares indicate significance at $p = 0.05$ after Holm correction.

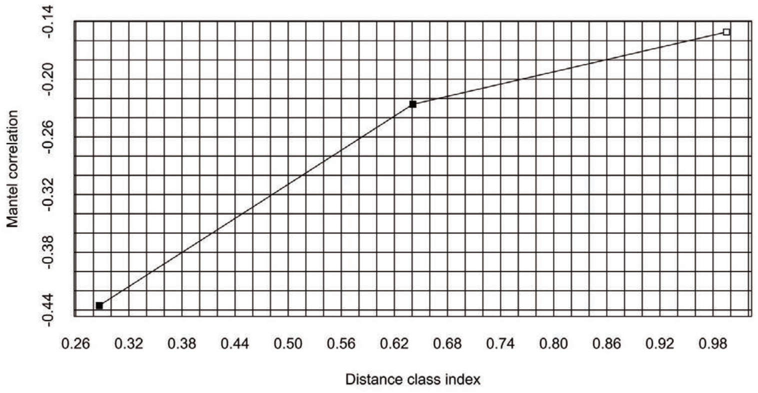

Figure 3.6: Mantel correlogram of the samples of Cyamudongo Forest. Significant correlations at $p = 0.05$ after Holm correction are indicated by black squares.

3.2 The Plant Communities

In the following section, the results of the cluster analyses are presented. The hierarchical clustering algorithm implemented into PC-Ord yields, especially on higher levels of the tree, far more plausible results than its R counterpart. Hence, the choice for WISHART'S (1969) function. The first approach by cutting the resulting tree dynamically is rather unorthodox, but especially in tropical vegetation yields results not obscuring details in species distribution. Since the dynamicTreeCut package (LANGFELDER, ZHANG & HORVATH, 2016) available for R is not applicable to results stemming from PC-Ord, local pruning has been done in consultation of the FCM-NC clustering results and was mainly led by species overlap and abundance. Neither is the dendrogram stemming from PC-Ord transferable to R nor could the algorithm underlying the hclust function of R be adapted since the one used in PC-Ord is based on unpublished material. The general order of the communities is derived from the results of the fuzzy c-means with noise clustering (FCM-NC) procedure. In order to achieve a logical consistency, the order has been changed where necessary. The dendrogram resulting from UPGMA is shown in Fig. 3.8. The membership matrix obtained by FCM-NC is displayed in annex 2. To establish a plant community on the grounds of a single, and additionally very small, sample does not fit the description of been scientifically sound. Even two sampling sites do not lend themselves to a robustly constructed vegetation unit. Thus, the names given respectively, of course, are of preliminary and purely descriptive nature.

3.2.1 *Dombeya torrida-Maesa lanceolata-Acalypha ornata* community

Fuzzy k-means cluster number: M1 + M24 + Noise X
UPGMA, local cut information level: 82%; 39% incl. 81_{Gw}
Plots: 85_{Gw}, 86_{Gw}, 89_{Gw}, 93_{Gw}, 81_{Gw} Locations: Gishwati Forest

M1+M24+N	85_{Gw}	86_{Gw}	89_{Gw}	93_{Gw}	81_{Gw}
85_{Gw}	0	0.48	0.47	0.45	0.79
86_{Gw}		0	0.57	0.57	0.84
89_{Gw}			0	0.51	0.83
93_{Gw}				0	0.76
81_{Gw}					0

Table 3.1: Bray-Curtis dissimilarities between the samples discussed.

M1+M24+N	85_{Gw}	86_{Gw}	89_{Gw}	93_{Gw}	81_{Gw}
85_{Gw}	0	0.37	0.94	0.33	0.42
86_{Gw}		0	1.26	0.04	0.78
89_{Gw}			0	1.22	0.57
93_{Gw}				0	0.74
81_{Gw}					0

Table 3.2: Geographic distances between the samples discused in km.

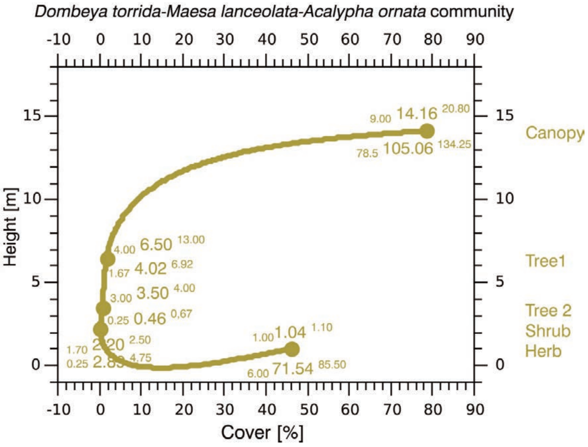

Figure 3.7: Cover-Height relation of the *Dombeya torrida-Maesa lancolata-Acalypha ornata* community; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

The four plots represent a vegetation type typical for some parts of the Gishwati Forest when it comes to the constellation of the tree layer–*Dombeya torrida* prevails almost to a pure stand. *Syzygium parvifolium* occurs in minor abundances in two plots (89_{Gw}, 93_{Gw}) as well as *Symphonia globulifera* (85_{Gw}, 93_{Gw}). Also, in only minor abundances, *Maesa lanceolata* occurs at three of the four sites. Except for plot 93_{Gw}, *Urera hypselodendron* can be found

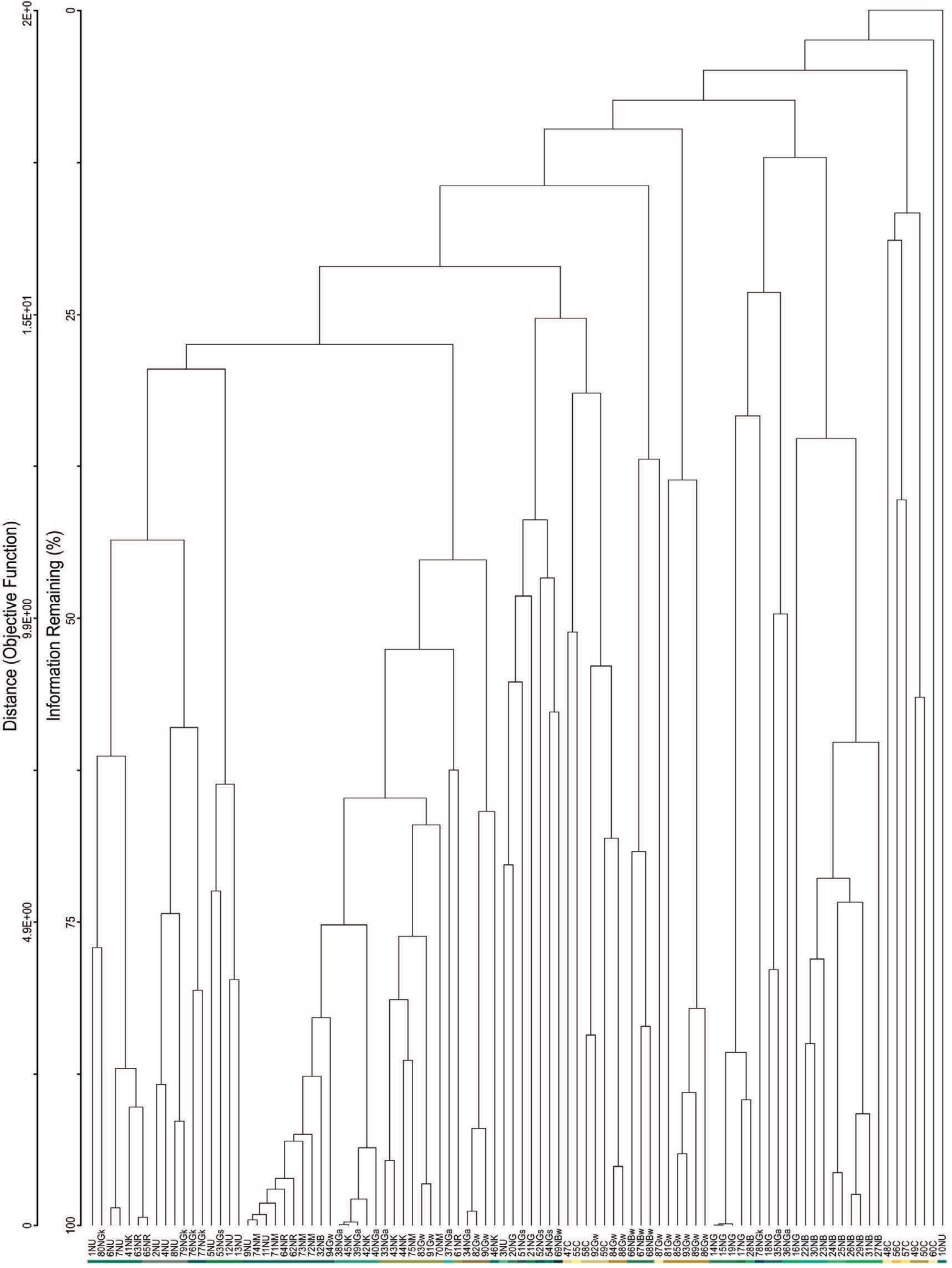

Figure 3.8: The dengrogram resulting from UPGMA. The chaining level is at 11.17 %. Calculations have been carried out using PC-Ord 7 (McCune & Mefford, 2018).

in all plots in low abundances. *Acalypha ornata* is present in three of the four stands, missing only at plot 86_{Gw}.

All plots are situated at about 2200 m a.s.l. with a mean annual temperature between 16.00 and 15.00 degree Celsius. Exposition ranges from NNE via NNW to SE. The loamy sands to sandy silts and clays cover a pH range from 3.70 to 4.88. The canopy, which covers two more tree layers, as well as a shrub and herb layer, reaches a maximum of 15 metres with an occasional emergent tree of about 20 metres.

Fischer & Hinkel (1994) do not describe a community with *D. torrida* prevailing. It is possible, however, to subsume the community found under the term "Niedrigstämmige Sekundärwälder" or low-stemmed secondary forests. Habiyaremye (1997) sticks to Lebrun & Gilbert's (1954) assignment to *Polyscietalia fulvae*. Drawing on species composition, the secondary character of the stand is not called into doubt. Thus, it seems plausible to integrate the community at hand into the alliance *Polyscion fulvae*. The title *Dombeya torrida-Maesa lanceolata-Acalypha ornata* community should provide adequate information. Somewhat broader in scope, a *Dombeya torrida* dominated secondary community would be an alternative denomination.

With a local cut at ca. 82% information level, UPGMA gives a result somewhat different to the fuzzy c-means. While FCM-NC places plot 89_{Gw} into a cluster of its own, UPGMA forms a quite dense group. Drawing on species composition, plot 89_{Gw} will not be separated into an independent cluster.

Another spatially close plot is site 81_{Gw}. Although the average Bray-Curtis dissimilarity value of 0.81 suggests to not merge the plot with the cluster, a closer look at species composition and geographical position enables a yet reluctant but feasible assignment of the sample to the vegetation unit just established. The location on the edge of a naturally open and saturated area gives an explanation as to the presence of species belonging to the Soncho-Bidentetea and the Mitragyno-Raphietalia. It could not be asserted if species are advancing from the *Dombeya* forest into the open area, if species inhabiting the open formation find suitable conditions within the forest or if this ecotone is stable over a prolonged period of time. The large dissimilarity may be somewhat relativised taking the hugely differing species number, as well as often nearly monotonic herb layers, into account. The differing species numbers are partially alleviated, in that the basis to all analyses is a data table without species, which only occurred once throughout the survey. Thus, as long as no further data is available, the site will be integrated into the vegetation unit formed, under the condition of being at the fringe of the formation.

Table 3.3: *Dombeya torrida-Maesa lanceolata-Acalypha ornata* community

Sample Site / Species	85_{Gw}	86_{Gw}	89_{Gw}	93_{Gw}	81_{Gw}
Exposition	NNE	SE	NNW	n/a	E
Inclination [°]	19	37	38	n/a	13
Position / Relief	HO	HU	HM	HU	KH
Precipitation / a [mm]	1389	1389	1376	1389	1378
Elevation a.s.l. [m]	2171	2230	2126	2224	2088
T S_{60} [°C]	16.00	15.50	15.00	16.00	15.00
pH	3.92	3.70	4.88	4.52	3.98
Soil texture	Sl	Sl	Us	Ts	Sl
Height t [m]	15	20.8	11	15	9
Height t1 [m]	4	13	4.5	6	5
Height t2 [m]	n/a	4	n/a	3	n
Height t3 [m]	n/a	n/a	n/a	n	n
Height Shrub [m]	2.30	2	2.5	1.7	2.5
Height Herb [m]	1.1	1	1.1	1	1
Height Moss [m]	n/a	n/a	n/a	n/a	n/a
Height juvenil [m]	n/a	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1	1	1
Vegetation Cover [Londo]	10	10	10	10	10
t Cover [%]	106.33	134.25	101.17	80.50	78.50
t1 Cover [%]	1.67	3.83	3.67	4.92	6.92
t2 Cover [%]	0	0.67	0	0.25	0
t3 Cover [%]	0	0	0	0	0
Shrub Cover [%]	3.83	0.25	4.75	0.01	2.75
Herb Cover [%]	74.58	80.08	85.5	69.25	46.00
Moss Cover [%]	0	0	0	0	0
Juvenil Cover [Londo]	p1	p1	p1	p1	p1
Juvenil Shrub Cover [Londo]	p1	p1	p1	n/a	n/a
Dombeya torrida	10	9	9	8	2
Urera hypselodendron	r1	r1	1.2		p1
Maesa lanceolata		p2	r1	p1	p1
Acalypha ornata	p4		p1	p1	p1
Syzygium parvifolium			p2	p2	p1
Thalictrum rhynchocarpum			p1	p1	p1
Carapa grandiflora	r2	p4			2
Achyranthes aspera	p1	r1			p2
Phyllanthus nummularifolius	p1			p2	p1
Symphonia globulifera	r1			r1	p1
Clerodendrum johnstonii			p1	r1	
Pilea sp. II			p1	p1	
Dichanthelium cf. hillebrandianum	p1	1.2			
Stephania cf. abyssinica	r1	r1			
Adenia bequaertii	r1	p1			
Polyscias fulva		2		r1	
Xymalos monospora		r1		p1	
Coccinia mildbraedii	p1				r1
Parochetus communis	p1				p1
Ipomoea sp.			p1		p1
Impatiens burtonii				4	p1
Gouania longispicata				p1	3
Elatostema monticola				p1	p1
Psychotria mahonii				r1	r1
Asplenium cf. sandersonii				r1	p1
Drymaria sp.				p1	p1

Table 3.3: *Dombeya torrida-Maesa lanceolata-Acalypha ornata* community (continued)

Sample Site / Species	85_{Gw}	86_{Gw}	89_{Gw}	93_{Gw}	81_{Gw}
Dryopteris sp. XIII				r1	p1
Mimulopsis cf. solmsii	2				
Gouania cf. longispicata	0.7				
Tectaria sp. III	r1				
Momordica cissoides	p1				
Clerodendrum sp. II	p2				
Acalypha sp.	p4				
Solanecio mannii	r1				
Asplenium cf. protensum	r1				
Asplenium mannii	r1				
Asplenium cf. mildbraedii	r1				
Acanthopale sp.	p2				
Pilea bambuseti		6			
Tabernaemontana stapfiana		2			
Tectaria coadunata		r1			
Diplazium sp. II		p2			
Selaginella sp.		m1			
Dryopteris sp. VIII		p2			
Dupineta cf. brazzae		p1			
Pteris sp. VIII		p1			
Alsophila manniana		r1			
Rytigynia sp. VIII		r1			
Clerodendrum cf. johnstonii		p1			
Pteris cf. pteridioides		p1			
Tectaria cf. coadunata		p1			
Asplenium sp. XVII		m1			
Pteris cf. preussii		p1			
Chassalia subochreata		r1			
Macaranga kilimandscharica		r1			
Tacazzea apiculata		r1			
Piper capense		p1			
Drymaria cordata		p1			
Isachne mauritiana			p1		
Dalbergia lactea			p1		
Solanum chrysotrichum			r1		
Vernonia sp. IV			p2		
Pilea rivularis			p1		
Girardinia bullosa			p1		
Croton megalocarpus			r1		
cf. Monanthotaxis orophila			r1		
Pilea cf. rivularis var. rivularis			p1		
Pilea sp. III				2	
Setaria megaphylla				p2	
Pavonia kilimandscharica				p1	
Drymaria cf. cordata				p1	
Viola abyssinica				p1	
Leucas sp.				p1	
Markhamia lutea				p1	
Keetia sp. II				r1	
cf. Mondia aff. whitei				p1	
Ramalina celastri				p1	
Asplenium cf. friesiorum				p1	
Pteris cf. dentata				r1	

Table 3.3: *Dombeya torrida-Maesa lanceolata-Acalypha ornata* community (continued)

Sample Site / Species	85_{Gw}	86_{Gw}	89_{Gw}	93_{Gw}	81_{Gw}
Crassocephalum montuosum				p1	
Psychotria cf. mahonii				r1	
Loxogramme abyssinica				p1	
Acalypha volkensii				p2	
Rubus cf. pinnatus				r1	
Adenochloa cf. claytonii				p1	
Pteris sp. IV				p1	3
cf. Vernonia sp. III					1.2
Pteris cf. microlepis					r1
Asplenium tenuicaudatum					r1
Bersama abyssinica					p2
Neoboutonia macrocalyx					p1
Ipomoea involucrata					r1
Myrianthus holstii					p1
Pilea johnstonii					p1
Dracaena laxissima					p1
Rubus cf. apetalus					r1
Asplenium protensum					r1
Cyperus sp. III					r1
Spermacoce princeae					r1
Basella alba					r1
cf. Microglossa sp.					p1
Dichanthelium hillebrandianum					r1
Psychotria peduncularis					p1
Celosia sp. I					p1
cf. Gladiolus dalenii					p1
cf. Hibiscus sp.					
Asplenium sp. X					p1
Gloriosa superba var. superba					p1
Polygonum sp.					r1
Momordica cf. friesiorum					p1
Gymnanthemum auriculiferum					p1
cf. Solanecio mannii					r1
Psychotria sp. IV					p2
Vernonia sp. II					r1
Psychotria sp. I					p2
cf. Galiniera sp.					r1
Lepidotrichilia volkensii					r2
Zehneria sp. I					p2
Persea americana					r1
Celosia sp. III					r1

Further species in the samples: Cucurbitaceae sp. XIX : **85**$_{Gw}$ p1, **86**$_{Gw}$ r1, **89**$_{Gw}$ p1; Gen. indet. spec. indet. CLXXIX : **86**$_{Gw}$ r1, **89**$_{Gw}$ p1, **81**$_{Gw}$; Cucurbitaceae sp. XVIII: **85**$_{Gw}$ p1, **86**$_{Gw}$ p1; Cucurbitaceae sp. XXI: **86**$_{Gw}$ r1, **93**$_{Gw}$ p1; **85**$_{Gw}$: Acanthaceae sp. X: 5-; Gen. indet. spec. indet. CXLVIII: r1; Apocynaceae sp. IX: p1; Asteraceae sp. V: r1; Cucurbitaceae sp. XX: p1; Gen. indet. spec. indet. CLXV: r1; Gen. indet. spec. indet. CXLV: p1; Woodsiaceae sp. IV: r1; Gen. indet. spec. indet. XVII: p2; Gen. indet. spec. indet. LVII: p1; Acanthaceae sp. IX p1; **86**$_{Gw}$: Acanthaceae sp. XI: p4; Gen. indet. spec. indet. CXXVI: p1; Fabaceae sp. III: r1; Gen. indet. spec. indet. CXXXV: r1; Poaceae sp. XII: m1; Cyperaceae sp. V: r1; Rosanae sp.: p1; Polypodiales sp. V: r1; **89**$_{Gw}$: Acanthaceae sp. XII: 8; Acanthaceae sp. VIII: p1; Woodsiaceae sp. V: p1; Fabaceae sp. II: p1; Gen. indet. spec. indet. LII: p2; **93**$_{Gw}$: Cucurbitaceae sp. XXII: r1; Cucurbitaceae sp.: r1; Cucurbitaceae sp. X: r1; Asteraceae sp. VII: p1; Rubiaceae sp. XIX: p1; Gen. indet. spec. indet. VI: r1; Euphorbiaceae sp.: p1; Gen. indet. spec. indet. IX: r1; Gen. indet. spec. indet. VII: r1; Rutaceae sp.: p2; Thelypteridaceae sp.: r1; Polypodiales sp. I: p1; **81**$_{Gw}$: Poaceae sp. VI: p1; Cucurbitaceae sp. III: r1; Cucurbitaceae sp. VIII: p1; Gen. indet. spec. indet. CXXVII: r1; Gen. indet. spec. indet. CLXXVIII: p1; Gen. indet. spec. indet. CLXXXI: p1; Gen. indet. spec. indet. CLXXXII: p1; Cucurbitaceae sp. XVII: p1; Cucurbitaceae sp. XII: p1; Gen. indet. spec. indet. CLXXXV: r1; Gen. indet. spec. indet. CLXXXVI: p1; Fabaceae sp. I: r1; Cucurbitaceae sp. XI: p1; Cucurbitaceae sp. IV: r1; Rubiaceae sp. XIII: p1; Poaceae sp. X: p1; Gen. indet. spec. indet. CLXXXVIII: r1; Rubiaceae sp. XIV: p1; Gen. indet. spec. indet. XXVII: p1; Gen. indet. spec. indet. CLXXXIII: r1; Rubiaceae sp. IV: r2; Rubiaceae sp. XV: r1; Gen. indet. spec. indet. CLXXX: p1; Gen. indet. spec. indet. CLXXXIX: r1

3.2.2 *Syzygium parvifolium-Alchornea hirtella* Community

Fuzzy k-means cluster number: M2

UPGMA local cut: 62% information level

Plots: 1_{NU}, 6_{NU}, 7_{NU}, 41_{NK}, 63_{NR}

Location: Uwinka, Kitabi, Ruzizi

M2	1_{NU}	6_{NU}	7_{NU}	41_{NK}	63_{NR}
1_{NU}	0	0.48	0.56	0.69	0.53
6_{NU}		0	0.34	0.55	0.43
7_{NU}			0	0.57	0.4
41_{NK}				0	0.5
63_{NR}					0

Table 3.4: Bray-Curtis dissimilarities between the samples discussed.

M2	1_{NU}	6_{NU}	7_{NU}	41_{NK}	63_{NR}
1_{NU}	0	0.27	0.24	25.14	14.16
6_{NU}		0	0.03	25.12	14.4
7_{NU}			0	25.13	14.38
41_{NK}				0	23.96
63_{NR}					0

Table 3.5: Geographic distances between the samples discused in km.

With about 31% to 66% resemblance between its members, the cluster is rather loosely confined. This feature is reflected in the slightly differing results for the clustering methods used. The fuzzy c-means places the plots 1_{NU}, 6_{NU}, 7_{NU}, 41_{NK} and 63NR into the same cluster. With UPGMA, an analogue cluster would be obtained by a local cut at the 62 % information level, additionally containing plots 80_{NGk} and 65_{NR}. Let's start with the cluster as it is and incorporate the UPGMA derived result subsequently.

Not very rich in species the five plots in Nyungwe Forest, with one near Kitabi at the eastern border, one at Ruzizi

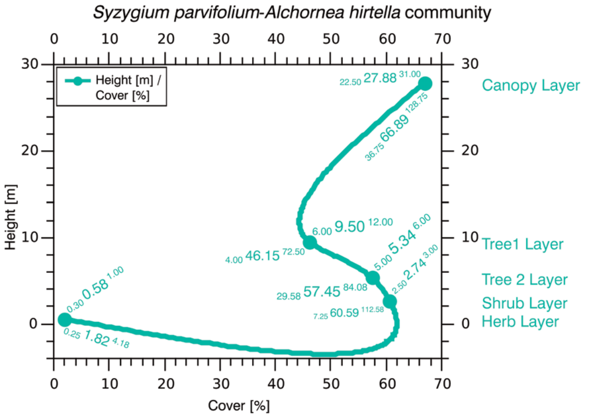

Figure 3.9: Cover-Height relation of the *Syzygium parvifolium-Alchornea hirtella* community; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

in the northern part just east of the watershed and three at Uwinka in the north-western part, harbour a community dominated by *Syzygium parvifolium* in the tallest tree layer. The crown layer sometimes has a share of *Newtonia buchananii* (6_{NU}), *Ocotea usambarensis* (7_{NU}) or *Olinia rochetiana* (41_{NK}, here dominant). Within all five sites, *Alchornea hirtella* can be found growing in high abundances in the shrub, third and second tree layer. Frequently, yet only in one plot with moderate abundance, *Chassalia subochreata* can be found in all plots. In three plots, *Parinari excelsa* can be found in little abundances. Also, only found in three plots, *Macaranga kilimandscharica* is present with little to high abundances. The herb layer shows little resemblance between the plots, only 6_{NU} and 7_{NU} as well as 41_{NK}, 65_{NR} and 63_{NR} have been placed within a discernible cluster by UPGMA and FCM alike. Despite some commonalities between the plots mentioned, only sparse juvenile cover and a few herbaceous species occur.

Adding the plots which have been grouped as well by UPGMA makes the cluster more heterogeneous. Plot 80_{NGk} near Gisakura is dissimilar to the other plots by up to 78%, which is mostly brought about by *Beilschmiedia rwandensis* being dominant in the tallest tree layer and quite a few species not being shared with the other sites. Moreover, plot 80_{NGk} holds a few species more than the other plots, which is mostly reflected in a greater developed herb layer. Though species composition agrees to a certain extent, it would be quite arbitrary to include plot 80_{NGk} into the cluster not least because of the huge differences in abundances and the high dissimilarities according to the Bray-Curtis index. Plot 65_{NR} has been placed close to plot 63_{NR} by UPGMA, which is in accordance with the Bray-Curtis dissimilarity of about 0.28. However, integrating the plot into the cluster is not as clear cut as it might be assumed to be. The fuzzy c-means places the plot within cluster M35 where plot 9_{NU} is the most similar site. Due to the overall higher similarity among the sites in cluster M35 and the higher membership values stemming from FCM-NC, plot 65_{NR} will not be included in the cluster at hand.

The altitude of all plots varies little around 2300 m a.s.l. Exposition of the plots ranges from NW via SSE to E. The mean annual temperature measured in the sandy to loamy soils stretches between 15.00 and 16.30 °C. The soil pH can get as low as 2.62 but does not exceed 3.85. The height of the canopy, which covers two to three more tree strata, reaches 20 to 28 metres. The herb layer is usually not well developed, while the shrub stratum can be almost non-existent or can cover the entire plot. The secondary character of the vegetation of these sites belonging to the mid-level cloud forest is beyond question. The classification into the order Polyscietalia fulvae also seems self-evident. However, a further assignment to existing categories poses quite a challenge. Elements of Fischer & Hinkel's (1993) *Carapa grandiflora-Symphonia* secondary forest can be found as well as of Fischer's (1996) *Albizia gummifera-Carapa grandiflora-Parinari excelsa* and *Albizia gummifera-Syzygium parvifolium-Macaranga communities*. Habiyaremye (1997) described the association Macarango-Psychotrietum mahonii. Despite the absence of most of the character species, *P. mahonii* itself is only present in negligible abundances, while *Macaranga* only occurs within two plots in reasonable abundances. *Syzygium* itself is only listed within the Ficalhoo-Podocarpetalia, which could not be confirmed by scrutinising the work of Lebrun & Gilbert (1954) which was the source given by Habiyaremye (1997). Alchornea hirtella, which is not listed by Habiyaremye (1997), is a formative part of these forest stands. For these quite dense and species-poor stands, a *Syzygium parvifolium-Alchornea hirtella* community could be established.

Table 3.6: *Syzygium parvifolium-Alchornea hirtella* community

Sample Site / Species	^{1}NU	^{6}NU	^{7}NU	^{41}NK	^{63}NR	^{80}NGk
Exposition	SSE	SW	NW	0	E	W
Inclination [°]	24	26	29	0	10	30
Position / Relief	HO	HO	HM	KS	KH	HO
Precipitation / a [mm]	1879	1879	1879	1631	1708	2486
Elevation a.s.l. [m]	2326	2304	2306	2342	2355	1902
T S_{60} [°C]	15.10	16.00	15.70	15.00		16.30
pH	2.72	2.62	2.73	2.73	3.20	3.58
Soil texture	Ts	Sl	Ts	Sl	Sl	Sl
t Height [m]	28	28.3	31	29.6	22.5	20.64
t1 Height [m]	6	12	8	10.52	11	12
t2 Height [m]	n/a	6	n/a	5	5	6
t3 Height [m]	n/a	n/a	n/a	n/a	n/a	n
Shrub Height [m]	2.5	3	3	2.7	2.5	3
Herb Height [m]	0.6	0.4	0.6	1	0.3	0.5
Moss Height [m]	0.001	n/a	0.02	0.004	n/a	n
Juvenil Height [m]	0.5	n/a	n/a	n/a	n/a	n
Epiphyts [m/6m]	1	0	1	1	1	1
Vegetation Cover [Londo]	10	10	10	10	10	10
t Cover [%]	36.75	65.00	128.75	47.33	56.67	105
t1 Cover [%]	4.00	51.42	30.50	72.33	72.50	32.25
t2 Cover [%]	0	29.58	0	58.67	84.08	57.75
t3 Cover [%]	0	0	0	0	0	0
Shrub Cover [%]	35.58	65.92	81.62	112.58	7.25	5.58
Herb Cover [%]	4.17	1.5	2.42	0.75	0.25	19.33
Moss Cover [%]	0	0	0	0.01	0	0
Juvenil Cover [Londo]	0.7	p2	m2	a2	a1	p2
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	n/a	n/a	p2
Alchornea hirtella	4	10	9	9	8	4
Syzygium parvifolium	3	4	9	1.2	6	0.7
Chassalia subochreata	p2	r1	p2	6	p2	p2
Parinari excellsa	0.7	1.2		p2		0.7
Psychotria mahonii	r1		p4	r1	r1	
Astropanax goetzenii	p4		p2			r2
Macaranga kilimandscharica		r2		3	7	
Salacia erecta		r1	r1	r1		
Asplenium sp. IV		r1	p1			p1
Ocotea usambarensis			3	0.7		
Mikaniopsis usambarensis				a2	p1	
Lasianthus kilimandscharicus	p1	p2				
Beilschmiedia rwandensis		2				8
Cleistanthus polystachyus		p2				p2
Warneckea walikalensis		r1				2
Rytigynia kigeziensis	p2		r1			
Symphonia globulifera		r1		1.2		
Carapa grandiflora		0.7		r2		
Newtonia buchananii		2	2			
Asplenium normale		p1	p1			
Strombosia scheffleri					r1	1.2
Allophylus chaunostachys				3		r1
Sericanthe leonardii	r1					
Asplenium erectum	r1					
Ficus aff. natalensis	r1					
Asplenium sp. II	r1					

Table 3.6: *Syzygium parvifolium-Alchornea hirtella* community (continued)

Sample Site / Species	1_{NU}	6_{NU}	7_{NU}	41_{NK}	63_{NR}	80_{NGk}
Asplenium cf. theciferum	r1					
Ocotea cf. usambarensis	r2					
Blotiella bouxiniana		r1				
Urera trinervis		r1				
Asplenium aff. loxoscaphoides		r1				
Brachystephanus holstii						2
Pleiocarpa pycnantha						0.7
Garcinia volkensii						r2
Tabernaemontana stapfiana						r1
Chlorophytum comosum						p1
Arthropteris cf. monocarpa						p1
Pentadesma reyndersii						r1
Asplenium sp. XLII						p1
Asplenium rukararense						p1
Mimulopsis cf. solmsii						p1
Ficus sp. VIII						r2
Urera hypselodendron						p1
Oxyanthus speciosus						p2
Asplenium dregeanum						m1
Pteris sp. III						p1
Dracaena laxissima						p1
Dichanthelium hillebrandianum						p1
Microcos mildbraedii						r2
Ficalhoa laurifolia			0.7			
Vittaria reekmansii			r1			
Asplenium cf. erectum			r1			
Asplenium sp. V			r1			
Asplenium sp. XXXVII			r1			
Asplenium sp. XIV			r1			
Olinia rochetiana				2		
Keetia gueinzii				p1		
Myrsine melanophloeos				p4		
Blotiella glabra				p1		
Rytigynia sp. III				r1		
Asplenium sp. VI					r1	
Ficus cf. ottonifolia					p4	

Further species in the samples: **1_{NU}**: cf. Canthium sp. p1; **80_{NGk}**: Rubiaceae sp. XII 0,7; Woodsiaceae sp. p2; **41_{NK}**: Bryopsida sp. V r1; Gen. indet. spec. indet. C p1; Gen. indet. spec. indet. XCIX r1; Bryopsida sp. IX; **63_{NR}**: Rubiaceae sp. IX p2

3.2.3 *Beilschmiedia rwandensis-Alchornea hirtella-Warneckea walikalensis* Community

Fuzzy c-means cluster number: Noise
Plot: 80_{NGk} Locations: Nyungwe, Gisakura

As has been discussed within the previous paragraph, plot 80_{NGk} offers some similarities to the sites constituting the *Syzygium parvifolium-Alchornea hirtella* community. Since the Rwandan endemic *Beilschmiedia rwandensis* has been described as a formative part of the Carapo-Beilschmiedietum rwandensis (HABIYAREMYE 1993), it would be negligent to allot the plot to cluster M2. Wistfully, the vegetation found does not correspond very well with the association established by Habiyaremye (1997). This, however, does not preclude the probability of finding a derivative of said vegetation unit. Since Habiyaremye (1997) described the community as occurring within the narrow range of 2080 - 2190 m a.s.l., the occurrence of a variation of the association is even more likely due to the lower altitude of the site at hand. Albeit Fischer & Killmann (2008) mention that the forest levels can be variable in their transitions by 100 m and up to 200 m. As far as the identified species allow, the vegetation could be characterised as primary forest or at least as a climax state.

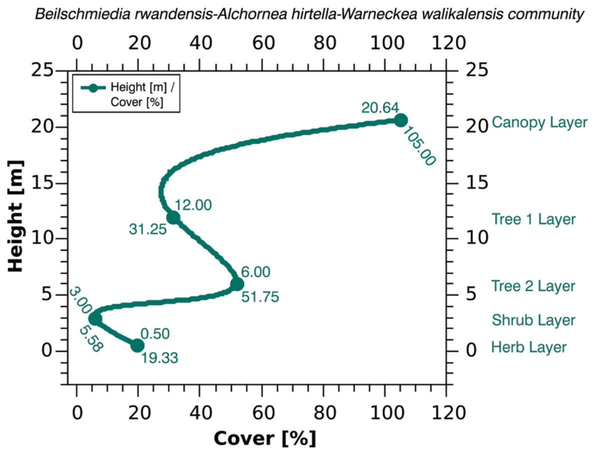

Figure 3.10: Cover-Height relation of the *Beilschmiedia rwandensis-Alchornea hirtella-Warneckea walikalensis* community; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Situated on sandy soil, the plot faces west at an altitude of 1900m a.s.l. Soil pH reaches 3.58, and the mean annual temperature is 16.30 °C. Three tree layers are present, the highest of which reaches 20.64 metres. Coverage by the shrub stratum is scarce, and the herb layer covers only little more.

In terms of classification, the utilisation of the Strombosio-Parinarietea, as the only class proposed to apply by Lebrun & Gilbert (1954), is not astonishing. Furthermore, the order Ficalhoo-Podocarpetalia and the alliance Galiniero-Parinarion excelsa (ex holstii Devred 1958) are applicable. Given that only two of the ten species indicative of the Carapo-Beilschmiedietum rwandensis are present in the site, an assignment to the association should not be made. Hence, a vegetation unit representative of the species composition of the site will be established–the *Beilschmiedia rwandensis-Alchornea hirtella-Warneckea walikalensis* community.

3.2.4 Standard Tree Secondary Community

Fuzzy k-means cluster number: M3 and M17
UPGMA local cut: 56 % information level
Plots: 49_C, 50_C
Dissimilarity (Bray-Curtis): 0.71

Location: Cyamudongo
Distance [km]: 0,31

Species inventory of plot 49_C in Cyamudongo Forest does not parallel the record of any other plot to an extent that would make a syntaxonomical treatment convenient. At least the moderate number of unidentified species does not amplify the issue. The fuzzy c-means places the plot in a cluster of its own while the UPGMA dendrogram points to some degree of similarity to plot 50_C, which is also in Cyamudongo, only a few 100 metres apart. The secondary membership of plot 49_C given by FCM-NC allots the plot with a minute fraction to the noise cluster. The respective tertiary and quaternary porbabilities of member ship as calculated by FCM-NC are reciprocal. Perusing the Bray-Curtis dissimilarity matrix, results in finding plot 92_{Gw} in Gishwati Forest to be the most similar to plot 49_C (BC-value: 0,70). This is followed by plot 50_C which has already been mentioned (BC-value: 0.71). Albeit a little more similar, plot 92_{Gw} should not be pooled with plot 49_C. The species number in common (3) does not suffice to construct a valid community or even to combine plots. Moreover, plot 92_{GW} is settled within another cluster which does not allow for the addition of plot 49_C. Species consistency with plot 50_C is much higher and, despite the abundances of the species in common being–at most–moderate, the most abundant species are formative of their respective layer. Notwithstanding, the 13 shared species do not yield for a stable community. Even considering that species distributions and occurrences can be sinusoidal, this does not lessen the reservations against an aggregation. Thus, both plots, 49_C and 50_C, should be treated as separate samples for now. The plots face ESE and SSE respectively, and both are set on sandy soils with little loam or clay admixture. In both cases, the soil is rather shallow, and in the case of plot 50_C, too shallow to measure the mean annual temperature, which in the case of site 49_C reaches 17.90 °C. Soil acidity varies between 3.13 and 3.21. Moreover, both sites hold three tree layers of which the canopy can reach 34 m (50_C) but does not fall below 24 m. The shrub cover is not well developed; while the herb layer of plot 49_C covers about 60%, the one of plot 50_C is about 12%.

Both plots show a secondary character, which is not an unusual trait for Cyamudongo Forest. Fischer & Hinkel (1993) described what they coined as “Hochstämmige Sekundärwälder” (standard tree secondary forest) for Cyamudongo Forest. However, the sparse data do not allow for any further classification as to the afore-mentioned descriptive category. Since *Elaeodendron buchananii* has not been mentioned for Cyamudongo, further field research has to be carried out to create a data basis on which an *Elaeodendron* characterised community could be established.

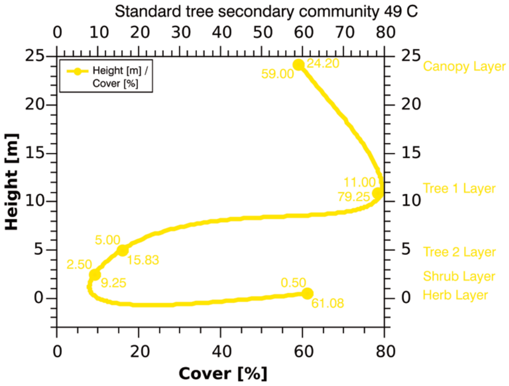

Figure 3.11: Cover-Height relation of the community recovered at plot 49 in Cyamudongo; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

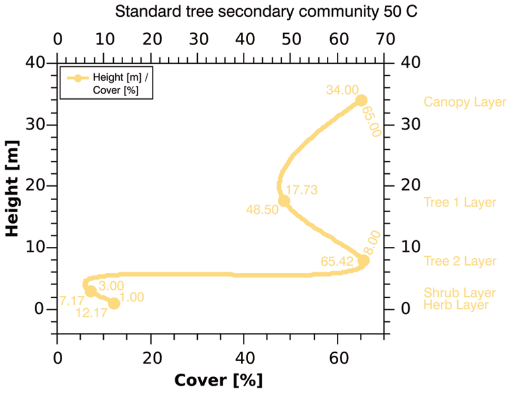

Figure 3.12: Cover-Height relation of the community recovered at plot 50 in Cyamudongo; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Table 3.7: Standard Tree Secondary Community

Sample Site / Species	49_C	50_C
Exposition	ESE	SSE
Inclination [°]	12	10
Position / Relief	KH	KH
Precipitation / a [mm]	1643	1643
Elevation a.s.l. [m]	1939	1987
T S_{60} [°C]	17.90	n/a
pH	3.13	3.32
Soil texture	Sl	St
t Height [m]	24.2	34
t1 Height [m]	7.85	17.73
t2 Height [m]	11	8
t3 Height [m]	n	n
Shrub Height [m]	2.5	3
Herb Height [m]	0.5	1
Moss Height [m]	n	n
Juvenil Height [m]	n	n
Epiphyts [m/6m]	1	1
Vegetation Cover [Londo]	10	10
t Cover [%]	59	65
t1 Cover [%]	79.25	48.5
t2 Cover [%]	15.83	65.42
t3 Cover [%]	n/a	n/a
Shrub Cover [%]	9.25	7.17
Herb Cover [%]	61.08	12.17
Moss Cover [%]	n/a	n/a
Juvenil Cover [Londo]	0.7	0.7
Juvenil Shrub Cover [Londo]	n	p1
Elaeodendron sp.	4	3
Vepris nobilis	2	r1
Symphonia globulifera	p1	r1
Macaranga kilimandscharica	r1	p2
Blotiella cf. bouxiniana	p1	r1
Carapa sp. nov.	p1	p1
Tabernaemontana odoratissima	p2	r1
Coffea eugenioides	p1	p2
Pleiocarpa pycnantha	r2	r1
Oxyanthus speciosus	p4	p4
Xymalos monospora	6	
Asplenium sp. XVII	5+	
Celtis durandii	2	
Maesa lanceolata	p4	
Culcasia falcifolia	r1	

Table 3.7: Standard Tree Secondary Community (contin.)

Sample Site / Species	49_C	50_C
Agelaea pentagyna	p1	
cf. Myrianthus holstii	r1	
Ficus sp. III	p1	
Gambeya cf. gorungosana	r1	
Salacia sp. II	r1	
Thunbergia vogeliana	r1	
Psychotria cf. mahonii	r1	
Pancovia golungensis		5-
Ritchiea albersii		1.2
Casearia runssorica		0.7
Polyscias fulva		0.7
Microcos mildbraedii		0.7
Chassalia subochreata		p2
Coccinia sp. I		r1
Aneilema aff. spekei		r1
Drypetes gerrardii		r1
Thunbergia sp. I		r1
Lasianthus cf. kilimandscharicus		r1
cf. Xymalos monospora		r1
Diospyros gabunensis		r4
cf. Polyscias fulva		r1
Salacia erecta		r1
Newtonia buchananii		p2
Asplenium sp. IV		p1
Rinorea angustifolia ssp. engleriana		r1
Dryopteris sp. XVI		r1
Tiliacora funifera		r1
Celtis gomphophylla		p2

Further species in the samples: Acanthaceae sp. : 49_C 0.7, 50_C p1; Poaceae sp. VI: 49_C p1, 50_C a2; Acanthaceae sp. II: 49_C, 50_C p1; 49_C: Commelinaceae sp. p1; Gen. indet. spec. indet. CXVII p1; Gen. indet. spec. indet. CXVIII r1; Malvaceae sp. r1; Gen. indet. spec. indet. CXXV r1; Rubiaceae sp. X r1; Gen. indet. spec. indet. LXXXII r2; Gen. indet. spec. indet. LXXX r1; Gen. indet. spec. indet. LXXVIII r4; Sapindales sp. r4; 50_C: Gen. indet. spec. indet. CXVI 3; Gen. indet. spec. indet. CXXXI r1

3.2.5 *Podocarpus latifolius-Isoglossa vulcanicola-Pilea rivularis* Community

Fuzzy k-means cluster number: M4

Plots: 22_{NB}, 23_{NB}, 30_{NB}

Locations: Nyungwe Mount Bigugu

M4	22_{NB}	23_{NB}	30_{NB}
22_{NB}	0	0.57	0.52
23_{NB}		0	0.61
30_{NB}			0

Table 3.8: Bray-Curtis dissimilarities between the samples discussed.

M4	22_{NB}	23_{NB}	30_{NB}
22_{NB}	0	0.09	0.89
23_{NB}		0	0.93
30_{NB}			0

Table 3.9: Geographic distances between the samples discused in km.

The three plots, 80 and about 930 metres apart, hold a vegetation community mostly dominated by *Podocarpus latifolius*. *Podocarpus* is then accompanied by *Psychotria mahonii* and *Maesa lanceolata*. The cluster described within the next paragraph offers quite a number of similarities. Compared to cluster M31, *Syzygium parvifolium* is not to be found, and *Myrsine melanophloeos* and *Mimulopsis excellens* recede. Next to *P. mahonii*, which also occurs in the second tree layer, *Gymnosporia acuminata* and *Urera hypselodendron* can be found. Only in one plot, 22_{NB}, has a well-developed third tree layer formed, which harbours regrowth of *Clutia abyssinica*, *Embelia schimperi*, *Gymnosporia acuminata*, *Galiniera saxifraga*, *Myrsine melanophloeos*, *Peddiea rapaneoides* and *Psychotria mahonii*. Except for *P. mahonii* (3), all abundances are rather low. One exemplar of *Embelia schimperi* is also found in plot 30_{NB}, solely constituting the third tree layer. Within the herb layer, *Impatiens gesneroidea* and *Coleus autranii* are shared by all three plots. The same is valid for *Isoglossa vulcanicola* with slightly higher abundances. *Pilea rivularis* and *Blotiella glabra* are in two sites each with moderate abundances. Positioned at an altitude of about 2900 m a.s.l., two of the three plots present a mean annual temperature of about 11°C. Though reaching approximately 60 cm of drillable soil depth, the ground did not permit the temperature to be measured in plot 23_{NB}. The pH level of the generally shallow soils ranges between 2.75 and 2.81. The mostly loamy to sandy soils of the sites are facing NE, NW and WNW, respectively. In one case, only one tree stratum has been reckoned; in another case three tree layers have been noted; while one of the sites has exhibited two layers. Overall, the canopy height varies between 20 and 32 metres.

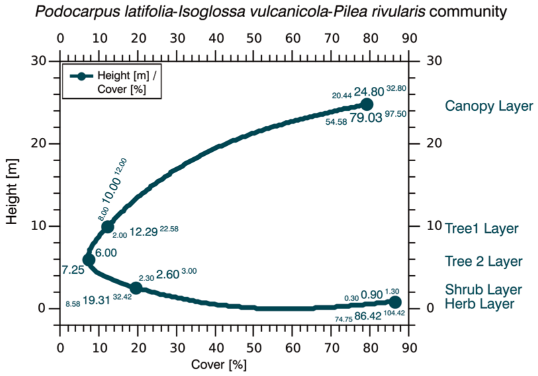

Figure 3.13: Cover-Height relation of the community recovered at Mount Bigugu; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Table 3.10: *Podocarpus latifolius-Isoglossa vulcanicola-Pilea rivularis* community

Sample Site / Species	22_{NB}	23_{NB}	30_{NB}
Exposition	NE	NW	WNW
Inclination [°]	22	15	11
Position / Relief	HO	HM	HM
Precipitation / a [mm]	1817	1817	1811
Elevation a.s.l. [m]	2922	2918	2885
T S_{60} [°C]	11.00	n/a	11.50
pH	2.81	2.78	2.75
Soil texture	Sl	Ls 2-3	Ls 2-3
t Height [m]	21.16	20.44	32.8
t1 Height [m]	12	n/a	8
t2 Height [m]	6	n/a	n/a
t3 Height [m]	n/a	n/a	n/a
Shrub Height [m]	2.5	2.3	3
Herb Height [m]	1.3	1	1
Moss Height [m]	0.002	n/a	n/a
Juvenil Height [m]	0.5	n/a	n/a
Epiphyts [m/6m]	1	1	1
Vegetation Cover [Londo]	10	10	10
t Cover [%]	97.5	85	54.85
t1 Cover [%]	22.58	0	2
t2 Cover [%]	7.25	0	0
t3 Cover [%]	0	0	0
Shrub Cover [%]	8.58	16.92	32.42
Herb Cover [%]	104.42	80.08	74.75
Moss Cover [%]	n/a	n/a	n/a
Juvenil Cover [Londo]	m4	n/a	n/a
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a
Podocarpus latifolius	10	7	5+
Impatiens gesneroidea	p1	p1	p2
Isoglossa vulcanicola	1.2	2	p2
Solenostemon sylvaticus	p1	r1	p1
Psychotria mahonii	0.7		p4
Urera hypselodendron	r1		r1
Embelia schimperi	r1		p1
Galiniera saxifraga	p2		p1
Pilea rivularis	3		5-
Maesa lanceolata	p4	2	
Blotiella glabra		1.2	2
Impatiens nyungwensis			1.2
Dryopteris sp. XII			0.7
Mimulopsis excellens			p4
Dryopteris sp. IX			p4
Zehneria sp.			p4
Gynura scandens			p2
Rubus sp. IX			p2
Asplenium mildbraedii			p1
Mikaniopsis tedliei			p1
Thalictrum rhynchocarpum			r1
Asplenium sp. XXXII			r1
Rubus sp. I			r1
Mimulopsis solmsii		4	
Hypolepis sparsisora		1.2	
Histiopteris incisa		p4	

Table 3.10: *Podocarpus latifolius-Isoglossa vulcanicola-Pilea rivularis* community (continued)

Sample Site / Species	22_{NB}	23_{NB}	30_{NB}
Coleus cf. maculosus subsp. edulis		p4	
Mikania cordata		p2	
Oreosyce africana		p2	
Crassocephalum ducis-aprutii		p2	
Rubus cf. apetalus		p1	
Cyperus sp. II		p1	
Ilex mitis		r1	
Dryopteris sp. I	5+		
Maytenus acuminata	p4		
Peddiea orophila	p2		
Myrsine melanophloeos	p2		
Rubus pinnatus	p2		
Asplenium sp. XV	p2		
Asplenium friesiorum	p1		
Asparagus asparagoides	p1		
Rubus steudneri	p1		
Racopilum africanum	p1		
Plagiochila cf. heterostipa	p1		
Cyperus sp.	p1		
Pilea cf. johnstonii	p1		
Asplenium sp. IV	p1		
Clutia abyssinica	r2		
Nuxia congesta	r1		
Impatiens gesneroidea		p1	p2
cf. Rubus sp. II	r1		

Further species in the samples: **22_{NB}**: Gen. indet. spec. indet. I r1; Impatiens gesneroidea p1; **23_{NB}**: Asteraceae sp. IV r1; Asteraceae sp. IV r1; **24_{NB}**: p1; Gen. indet. spec. indet. II r1; Gen. indet. spec. indet. CLXXVI p1; Gen. indet. spec. indet. LXXIX r1; **25_{NB}**: Impatiens gesneroidea p1; cf. Senecio mariettae p1; Poaceae sp. II p1; Poaceae sp. I r1

The fuzzy c-means algorithm and UPGMA (with a local cut at the 78% information level) give analogous results. The high dissimilarities according to the Bray-Curtis index leave the classification prone to some doubt. A classification into the *Podocarpus* forests of the upper cloud forest (Fischer, 1996) or upper montane forest (Fischer & Killmann, 2008) presents no difficulty. Fischer and Killmann (2008, p. 16) mention that *Mimulopsis solmsii* is an abundant shrub and that the herb layer mainly consists of ferns. Both prove to be the case, yet this only occurs within one plot each, making similarities more inconspicuous and a strict classification arbitrary. Nevertheless, the order Ficalhoo-Podocarpetalia seems to be applicable. However, any further classification into existing units seems inappropriate. In distinction to cluster M31, a *Podocarpus latifolius-Isoglossa vulcanicola-Pilea rivularis* community could be established.

3.2.6 *Hagenia abyssinica* Dominated Secondary Community

Fuzzy k-means cluster number: M6
UPGMA, local cut information level: 79 %
Plots: 18_{NG}, 35_{NGa} Locations: Nyungwe, Gisovu, Gahurizo
Dissimilarity (Bray-Curtis): 0.58 Distance [km]: 40.91

Hagenia abyssinica dominates both sites in the tallest stratum. In the herb layer, *Asplenium* *mildbraedii* and *Phyllanthus nummulariifolius* are present in both plots although only in minute abundances. The same is valid for *Polygala ruwenzoriensis*, *Veronica abyssinica* and *Drymaria cordata*. Plot 18_{NG} also holds *Agarista salicifolia* in very small abundances in the canopy layer. *Nuxia congesta* can be found in the second tallest layer, and a yet unidentified *Panicum* species dominates the herb layer. Within plot 35_{NGa}, *Macaranga kilimandscharica* can be found in the tallest stratum. Though not well developed, the second tallest layer within the site harbours *Xymalos monospora* and *Syzygium parvifolium* in minor abundances. The herb layer of the plot is dominated by *Isachne mauritiana*.

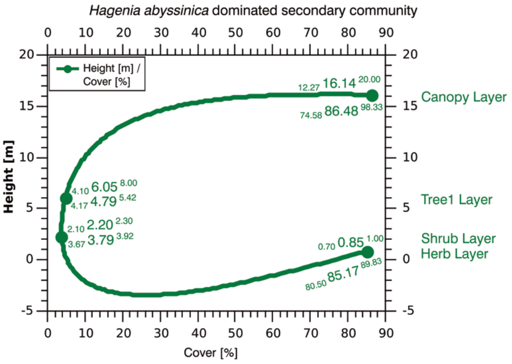

Figure 3.14: Cover-Height relation of the community recovered at Gahurizo; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

The altitudinal range of the site's positions is between 2524 and 2600 m without any expositional preference. Within plot 18_{NG}, the drillable soil depth reaches 1.50 m within plot 35_{NGa} 0.6 m. Soil pH ranges between 3.95 and 3.38, while the mean annual temperature reaches about 15°C in plot 35_{NGa}. Both sites hold two tree layers, which in the case of plot 35_{NGa} reach a canopy height of 12 m, and in case of site 18_{NG} a height of 20 m. Both methods, UPGMA and FCM-NC, place the plots in the same cluster. With UPGMA this is achieved by a local cut at the 79% information level.

As Fischer & Killmann (2008, p. 298) wrote, *Hagenia abyssinica* also occurs outside the upper level of montane forest (2600m-2900m) and can form an altitudinal belt from 2000-3600 m a.s.l. in conjunction with *Hypericum revolutum*. The vegetation recorded does not allow any direct classification. Species combination only allows for the conjecture that the sites hold vegetation close to the mentioned *Hagenia-Hypericum* belt. Fischer (1996) described a *Hagenia abyssinica* secondary forest for the Kahuzi-Biega national park. Here, the formation also offers quite a few similarities to the vegetation at hand. Classification into the *Hagenietum abyssinicae* (Lebrun 1942) Demaret 1958 may be feasible. The rationale, in this case, is the same as with the one previously mentioned; species composition is close but – keeping the caveats in mind – a classification is not warranted. The placement within the alliance Polyscion fulvae (Lebrun & Gilbert 1954), on the other side, is justified in regard to species composition. Even combining both plots might not be a final judgment. Taking the largely differing herb layers into account, especially with respect to the predominant species, the community concocted might be of a higher syntaxonomic order. As a preliminary designation, a *Hagenia abyssinica* dominated secondary community has to suffice.

3.2.7 *Hagenia abyssinica-Erica mannii-Lycopodium clavatum* Successional Community

Fuzzy k-means cluster number: M8
UPGMA, local cut information level: 50 %
Plots: 36_{NGa} Locations: Nyungwe, Gahurizo
Dissimilarity (Bray-Curtis): 72 % (to most similar, 17 NG)
Distance [km]: 40.30 (to 17NG), 0.12 (to closest, plot 35 NGa)

Plot 36_{NGa} has been cast into a cluster of its own by FCM-NC. With UPGMA the site branches already at the 50% information level of the dendrogram. The canopy of the quite open stand is made up of *Erica mannii* and *Hagenia abyssinica* as the dominant species. With quite low abundances, *Senecio maranguensis*, *Hypericum revolutum* and *Syzygium parvifolium* complete the inventory of the tallest layer. The obvious secondary character is underlined by the presence of *Pteridium aquilinum* and the regrowth of *Hagenia abyssinica* in the shrub layer. The herb layer is constituted mostly of *Lycopodium clavatum*, an indication of the open character of the stand an probably the acidic soil conditions.

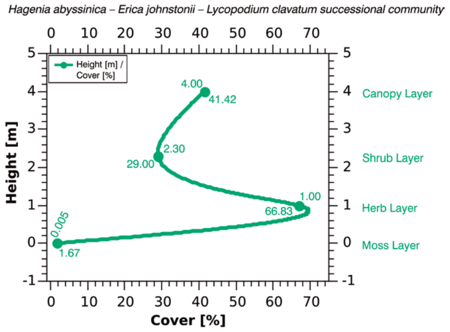

Figure 3.15: Cover-Height relation of the community recovered at Gisovu and Gahurizo; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

The ESE facing site is situated at an altitude of about 2500 m. The mean annual temperature measured at 60 cm soil depth reaches about 14°C. The drillable soil depth reaches about 1 m and the pH of said soil is 3.39. The sole tree layer is only about 4 metres high and covers a somewhat well-developed shrub layer and a herb layer that covers about 67% of the site.

With 72% and 74% dissimilarity, respectively, plots 17_{NG} and 35_{NGa} are most similar to plot 36_{NGa}. The secondary assignment by FCM-NC for plot 36_{NGa} is to the noise cluster. According to the UPGMA dendrogram, plots 18_{NG} and 35_{NGa}, which constitute cluster M6, are closer to sample site 36_{NGa} then is plot 17_{NG}. The similarity of the plot around Gisovu is mostly created by the presence of Erica *mannii*. Further parallels are almost non-existent, and taking the 72% dissimilarity into account, a grouping of the plots is out of the question. Though plot 35_{NGa} is spatially close, species composition and morphology of the stand differ largely. While plot 35_{NGa} features a second tree layer and canopy cover is beyond 95%, plot 36_{NGa} exhibits one tree layer only, which is quite open. A closer look at a satellite picture reveals the differences at a glance and shows that the area plot 36_{NGa} is situated in might have been impacted by a fire. Thus, ecological conditions have been altered, which then axiomatically brought about a change in species composition and abundance distribution. The heightened *L. clavatum* abundance and the presence of different *Rubus* species are a sign of the modified environmental conditions. Also, the presence of *E. mannii* could give rise to the presumption of a fire inflicted community formation. According to Troupin (1985), *Erica mannii* prefers scrubs and clearings mostly on stony ground and on ridges. Here, all the conditions are met. Seemingly, since site 35_{NGa} offers almost the same conditions, the time which elapsed after the disturbance has a ruling within the species composition. It is to be assumed that the vegetation cover of plot 35_{NGa} could have also been found in plot 36_{NGa} before the supposed fire. In essence, the establishment of a joint vegetation unit of plots 18_{NG}, 35_{NGa} and 36_{NGa} is not to be advised. Site 36_{NGa} should remain in a cluster of its own that represents a successional community. The combination of *Hagenia abyssinica* and *Erica mannii* especially represents a vegetation assembly not often seen in Nyungwe Forest. A provisional denomination could be a *Hagenia abyssinica-Erica mannii-Lycopodium clavatum* successional community.

Table 3.11: *Hagenia abyssinica-Erica mannii-Lycopodium clavatum* successional community
Hagenia abyssinica dominated secondary community

Sample Site / Species	^{18}NG	^{35}NGa	^{36}NGa
Exposition	NW	SE	ESE
Inclination [°]	38	22 to 29	26
Position / Relief	HO	HM	HO
Precipitation / a [mm]	1626	1665	1675
Elevation a.s.l. [m]	2600	2524	2533
T S_{60} [°C]	n/a	14.9	14
pH	3.95	3.38	3.39
Soil texture	Sl	Sl	Sl
t Height [m]	20	12.27	4
t1 Height [m]	8	4.1	n
t2 Height [m]	n/a	n/a	n
t3 Height [m]	n/a	n/a	n
Shrub Height [m]	2.3	2.1	2.3
Herb Height [m]	0.7	1	1
Moss Height [m]	n/a	0.01	0.005
Juvenil Height [m]	n/a	n/a	n
Epiphyts [m/6m]	1	1	n
Vegetation Cover [Londo]	10	10	10
t Cover [%]	74.58	98.33	41.42
t1 Cover [%]	5.42	4.17	0
t2 Cover [%]	0	0	0
t3 Cover [%]	0	0	0
Shrub Cover [%]	3.92	3.67	29
Herb Cover [%]	89.83	80.5	66.83
Moss Cover [%]	n/a	n/a	0
Juvenil Cover [Londo]	p1	a2	a2
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a
Hagenia abyssinica	7	8	3
Pteridium aquilinum	p1	p2	0.7
Hypericum revolutum	r1	p1	p2
Phyllanthus nummularifolius	p1	a2	p1
Polygala ruwenzoriensis	r1	p1	p1
Drymaria cordata	m2	m2	
Asplenium mildbraedii	m1	a1	
Veronica abyssinica	p1	r1	
Asplenium sp. IV	p1	p1	
Erica mannii	p1		3
Senecio maranguensis	r1		0.7
Dracaena afromontana	r2		r1
Isachne mauritiana		7	p1
Lycopodium clavatum		p1	5+
Syzygium parvifolium		p2	r1
Virectaria major		p2	0.7
Ipomoea involucrata		p2	p1
Maesa lanceolata		p1	r1
Asplenium friesiorum		p1	p1
Peltigera dolichorhiza		p1	r1
Helichrysum sp. II		p1	r1
Panicum sp.	8		
Nuxia congesta	0.7		
Rubus sp.	p2		

Table 3.11: *Hagenia abyssinica-Erica mannii-Lycopodium clavatum* successional community
Hagenia abyssinica dominated secondary community

Sample Site / Species	^{18}NG	^{35}NGa	^{36}NGa
Clematis simensis	r1		
Helichrysum cf. foetidum	r1		
Agarista salicifolia	p2		
Geranium arabicum	p1		
Gynura scandens	r1		
Acalypha manniana	r1		
Mikania cordata	p1		
Helichrysum sp.	r1		
Helichrysum sp. I	r1		
Mikaniopsis sp.	p1		
Hedythyrsus thamnoideus	r1		
Dryopteris sp. IV	r1		
Cyperus sp. IX	r1		
Senecio sp.	r1		
Senecio sp. I	p1		
cf. Vernonia sp.	r1		
Adenochloa adenophora	m2		
Macaranga kilimandscharica		1.2	
Galiniera saxifraga		r1	
Maytenus acuminata		r1	
Xymalos monospora		p4	
Myrsine melanophloeos		r1	
Asplenium cf. friesiorum		p1	
Oreosyce africana		r1	
Cyperus sp. III		p2	
Crassocephalum vitellinum		p1	
cf. Virectaria major		r1	
Festuca sp.		p2	
cf. Poa leptoclada		r1	
Poecilostachys oplismenoides		p1	
Senecio sp. II		r1	
Cyanotis vaga		p1	
Rumex sp.		p1	
Alchemilla kiwuensis		p1	
Dichanthelium hillebrandianum		p1	
Senecio cf. subsessilis		r1	
Anisopappus sp.		p1	
Pycnostachys goetzenii		p2	
Sibthorpia europaea		r1	
Otiophora pauciflora ssp. burttii			a1
Rubus cf. steudneri			p1
Dichanthelium cf. hillebrandianum			a1
Pycnostachys meyeri			p1
Bryopsida sp. V			p2
Rubus sp. V			p1
cf. Helichrysum sp. III			r1
Rubus sp. VI			p2
Rumex cf. abyssinicus			p1
Syzygium parvifolium			r1

Further species in the samples: **18_{NG}**: Asteraceae sp. r1; Asteraceae sp. IX r1; Gen. indet. spec. indet. LI p2; Gen. indet. spec. indet. LXX p1; Polypodiales sp. XXIII r1; **35_{NGa}**: Spermacoce princeae p1; Gen. indet. spec. indet. XC m1; **36_{NGa}**: Asteraceae sp. I p1; Bryopsida sp. IX r1

3.2.8 Ericetum johnstonii Habiyaremye & Lejoly (1993)
Erica mannnii Dominated Ecotonal Community

Fuzzy k-means cluster number: M34
Plots: 17_{NG}, 28_{NB}
Dissimilarity (Bray-Curtis): 0.49
Locations: Nyungwe Gisovu, Mt. Bigugu
Distance [km]: 14.5

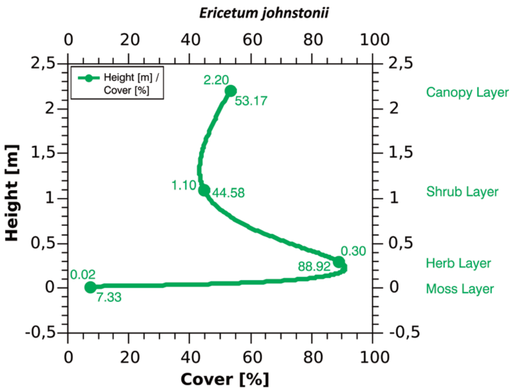

Figure 3.16: Cover-Height relation of the Ericetum johnstonii; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

About 14 km, apart one plot around Gisovu and one plot on Mt. Bigugu, support vegetation with low canopy height, which is mainly constituted by *Erica mannii*; Mt. Bigugu has an admixture of *Maesa lanceolata* and *Gymnosporia acuminata*, and Gisovu has *Faurea saligna*. This is not the only difference between those stands. Starting with the vertical structure, there are two obvious distinctions: the total height and the stratification. At Gisovu, *E. mannii* reaches a maximum height of 2.5 m and vegetation only comprises a tree, a shrub, a herb and a moss layer. On Mt. Bigugu this is somewhat different. The canopy layer is about 9 m high followed by a second tree layer of about 4 m height and a shrub layer reaching the height of the tree layer at Gisovu. The plots are situated at an altitude of about 2750 m and face NE and ENE, respectively. Soil depth does not exceed 38 cm at both sites; thus, the mean annual temperature could not be determined. Since both soils are quite shallow and the drillable soil depth is limited by stone, a sample of the sandy soils sufficient to measure pH could also not be drawn.

Both, UPGMA and FCM-NC offer the same solutions. Though *E. mannii* occurs in high abundance in all plots, a closer look reveals that, besides *Erica* there are very few commonalities. Since *Maesa lanceolata* and *Faurea saligna* have not been found jointly throughout the survey and considering the differences mentioned above, it seems to be of merit to break this cluster up into two communities. Habiyaremye (1997) called what has been found on Mt. Muzimu *Philippietum johnstonii* (Habiyaremye & Lejoly, 1993). However, the community at hand could be placed into this classification, calling it *Ericetum johnstonii*, which corresponds with the Ericaceous shrub described by Fischer and Killmann (2008).

The community encountered on Mt. Bigugu still harbours *P. latifolius*, which is nearing its altitudinal limit here. Also, *Gymnosporia acuminata* (2400m) and *Maesa lanceolata* are at their respective limits. Species composition of plot 28_{NB} suggests a transition between the upper montane forest and the Ericaceous shrub. The location of the assumed ecotone is consistent with the altitudinal limits given in Fischer and Killmann (2008).

Table 3.12: Ericetum johnstonii Habiyaremye & Lejoly 1993
Podocarpus-Erica mannii-Asplenium friesiorum primary forest
Erica mannnii dominated ecotonal community

Sample Site / Species	24_{NB}	25_{NB}	28_{NB}	17_{NG}
Exposition	NW	NNE	ENE	NE
Inclination [°]	20	18	31	10
Position / Relief	HO	HO	HO	HO
Precipitation / a [mm]	1818	1810	1808	1643
Elevation a.s.l. [m]	2928	2923	2772	2751
T S_{60} [°C]	11.50	11.90	n/a	n/a
pH	2.61	2.81	2.88	3.56
Soil texture	Sl	Sl	Sl	Sl
t Height [m]	8	11	9	2.5
t1 Height [m]	5.5	7	4	n/a
t2 Height [m]	n/a	n/a	n/a	n/a
t3 Height [m]	n/a	n/a	n/a	n/a
Shrub Height [m]	2	2.5	2.5	1.1
Herb Height [m]	0.6	0.6	1	0.3
Moss Height [m]	0.03	0.05	0.05	0.02
Juvenil Height [m]	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1	0
Vegetation Cover [Londo]	10	10	10	10
t Cover [%]	98	33.17	92.08	53.17
t1 Cover [%]	38.5	121.08	0.67	0
t2 Cover [%]	0	0	0	0
t3 Cover [%]	0	0	0	0
Shrub Cover [%]	7.75	7.17	11.08	44.58
Herb Cover [%]	38.83	37.33	52.83	88.92
Moss Cover [%]	n/a	n/a	n/a	n/a
Juvenil Cover [Londo]	p2	p2	n/a	p1
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	n/a
Erica mannii	7	3	9	6
Podocarpus latifolius	6	9	p2	
Maytenus acuminata	r1	p4	0.7	
Asplenium mildbraedii	2	p4	p1	
Myrsine melanophloeos	p4	p4	p4	
Asplenium friesiorum	p2	2	1.2	
Phyllanthus nummularifolius		p1	p1	
Maesa lanceolata		r1	p2	
Rubus cf. steudneri		p1	p2	
Hedythyrsus thamnoideus		p1	p2	
Breutelia diffracta		r1	3	
Psychotria mahonii	p1	0.7		
Galiniera saxifraga	r1	p2		
Gynura scandens	p1	p1		
Asplenium cf. protensum	m1	p2		
Racopilum africanum	p2	m4		
Pilea cf. johnstonii	m1	r1		
Atractylocarpus sp.	r1	p1		
cf. Senecio mariettae	p1	p1		
Cyperus sp. II	p1	p1		
Dryopteris sp. XII	p1	p2		
Otiophora pauciflora ssp. burttii			0.7	r1
Senecio sp. IV			0.7	

Table 3.12: Ericetum johnstonii Habiyaremye & Lejoly 1993
Podocarpus-Erica mannii-Asplenium friesiorum primary forest
Erica mannii dominated ecotonal community (continued)

Sample Site / Species	24NB	25NB	28NB	17NG
Mikania cordata			r1	
Tacazzea apiculata			p1	
Asplenium sp. IV			p1	
Asplenium sp. XXII			p1	
Cyperus sp. I			r1	
Asplenium sp. XX			p2	
Hydrocotyle sp.			p1	
Centella asiatica			p1	
Elaphoglossum cf. rwandense			p2	
Peucedanum runssoricum			m4	
Senecio mariettae			p1	
Mimulopsis excellens	1.2			
Plagiochila cf. squamulosa	0.7			
Isoglossa vulcanicola	p2			
Blotiella glabra	p1			
Elaphoglossum cf. kivuense	p1			
Bothriocline ruwenzoriensis	p1			
Asparagus asparagoides	p1			
cf. Ficus sp. X	r1			
cf. Lychnis kiwuensis	r1			
cf. Coleus maculosus subsp. edulis	p1			
Grammitis flabelliformis	p1			
Stellaria mannii	p1			
Peucedanum sp.	p1			
cf. Isoglossa sp. I	p1			
Elaphoglossum cf. aubertii	p1			
Clematis cf. grandiflora	p1			
Peddiea cf. rapaneoides	p4			
Syzygium parvifolium		2		
Rytigynia kigeziensis		r1		
Impatiens gesneroidea		p1		
Clutia abyssinica		r1		
Peddiea orophila		p4		
Hypericum cf. revolutum		r1		
Olea capensis ssp. hochstetteri		r1		
cf. Afroligusticum runssoricum		p1		
Rubus cf. apetalus		p1		
Pittosporum mildbraedii		p4		
Polystachya leonardiana		p1		
Elaphoglossum kivuense		p1		
cf. Vaccinium stanleyi		p1		
Vaccinium stanleyi		p1		
Elaphoglossum tanganjicense		p1		
Ardisiandra wettsteinii		r1		
Elaphoglossum aubertii		m1		
cf. Stellaria mannii		r1		
Plagiochila squamulosa		m2		
Trachypodopsis sp.		p1		
cf. Aristida adoensis				9
Erica kingaensis				4
Faurea saligna				r1

Table 3.12: Ericetum johnstonii HABIYAREMYE & LEJOLY 1993
Podocarpus-Erica mannii-Asplenium friesiorum primary forest
Erica mannii dominated ecotonal community (continued)

Sample Site / Species	24_{NB}	25_{NB}	28_{NB}	17_{NG}
Scleria distans				p1
Struthiola thomsonii				p1
Kotschya aeschynomenoides				r1
Campylopus sp.				p2
Pyrrhobryum spiniforme				p1
Sporobolus sp.				p1
Adenochloa adenophora				p1

Further species in the samples: **17_{NG}**: Bryopsida sp. VIII p4; Poaceae sp. III r1; Poaceae sp. IV r1; Lichen sp. I p2; **28_{NB}**: Poaceae sp. VII p1; Polypodiales sp. XV r1; **24_{NB}**: Gen. indet. spec. indet. II r1; Gen. indet. spec. indet. CLXXVI p1; Gen. indet. spec. indet. LXXIX r1; Gen. indet. spec. indet. III r1; Trichomanes sp. m1; **25_{NB}** : Bryopsida sp. X r1; Poaceae sp. II p1; Poaceae sp. I r1; Gen. indet. spec. indet. r1; Polypodiales sp. XXV p2; Trichomanes sp. I p1; Polypodiales sp. XX 0.7

3.2.9 *Podocarpus-Erica mannii-Asplenium friesiorum* Community *Erica mannii* Dominated Ecotonal Community

Fuzzy k-means cluster number: M7 / M34
UPGMA, local cut information level: 96 %, 7 %
Plots: 24_{NB}, 25_{NB}, 28_{NB}
Locations: Nyungwe, Bigugu

M7 / M34	24_{NB}	25_{NB}	28_{NB}
24_{NB}	0	0.43	0.55
25_{NB}		0	0.69
28_{NB}			0

Table 3.13: Bray-Curtis dissimilarities between the samples discussed.

M7 / M34	24_{NB}	25_{NB}	28_{NB}
24_{NB}	0	0.32	1.35
25_{NB}		0	1.51
28_{NB}			0

Table 3.14: Geographic distances between the samples discused in km.

In consideration of the BRAY-CURTIS values and vegetation composition, the UPGMA and FCM-NC solutions pertaining to cluster M7 will be discussed in this section, whereby, the vegetation of plots 24_{NB} and 25_{NB} will be outlined. The fragment consisting of plot 28_{NB} of the cluster dissolved in the previous paragraph will be modified under the rationale to be discussed.

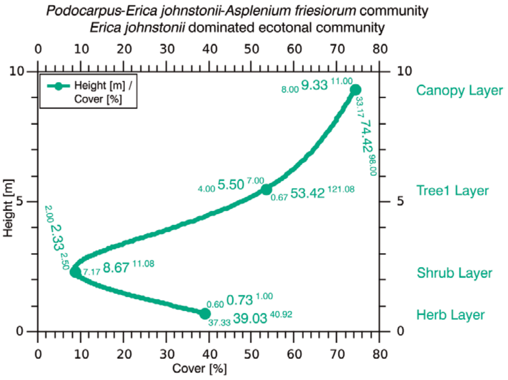

Figure 3.17: Cover-Height relation of the ecotonal community; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

At the summit region of Mt. Bigugu, two plots have been grouped by UPGMA and FCM-NC within which *Erica mannii*, interspersed mostly with *Podocarpus latifolius*, is prevailing in the tree layer. However, in plot 25_{NB}, *Podocarpus* is not found in the tallest but in the second tallest tree stratum, here almost as a pure stand. In plot 24_{NB}, the canopy layer also holds *Psychotria mahonii*, *Myrsine melanophloeos* an unidentified *Ficus sp*. and *Clematis cf. grandiflora*. *Syzygium parvifolium* and *Gymnosporia acuminata* are found in plot 25_{NB} in minor abundances. Here, the second tallest tree layer is well developed with *S. parvifolium*, *G. acuminata*, *Galiniera saxifraga*, *Peddiea rapaneoides*, *Psychotria mahonii*, *Pittosporum mild-*

braedii and *R. melanophloeos* in little abundances.

NW and NNE facing, both sites are positioned around 2900 m a.s.l. The mean annual temperature does not exceed 12°C and the drillable soil depth ranges between 0.56 and 0.68 m. The texture of the shallow soils is sandy with little loam percentage. Within both plots, there are only two tree layers, with the tallest one only reaching up to 11 m.

None of the literature reviewed allows for an incorporation of the sample into an existing classification (cf. all Lit cited). The sites seem to be of an ecotonal nature between upper montane forest and ericaceous shrub, judging from species composition and morphology. This brings cluster M34 back to mind, especially plot 28_{NB} on Mt. Bigugu. Both UPGMA and FCM-NC place plots 17_{NB} and 28_{NB} in direct connection as well as plots 24_{NB} and 25_{NB}. Both groups are then joined quite late by UPGMA (7% info level). The secondary membership of plot 28_{NB}, according to FCM-NC, would be cluster M36, which will be discussed at a later point. The secondary membership of plot 24_{NB} computed by FCM-NC is then cluster M34 which puts the site closer to plot 28_{NB}. The Bray-Curtis index corroborates the classification into different clusters to a certain extent. Yet, a closer look at species composition and abundance distribution explains, on the one hand, the high dissimilarities between the sites. On the other hand, it puts the elevated dissimilarity into perspective and opens up the possibility to integrate plot 28_{NB} into the cluster comprising plots 24_{NB} and 25_{NB}. Still precarious, the community might be called *Podocarpus-Erica mannii-Asplenium friesiorum*. Since an ecotone harbours species from more than one syntaxonomic unit, more permissive conduct in categorisation might be allowed. Therefore, another suggestion would be to establish a broader terminology; for example, the *Erica mannii* dominated ecotonal communit. Both designations could be settled within low-stemmed tree primary forests respectively.

3.2.10 *Erica mannii-Aristida adoensis* Community
Erica mannii-Faurea-Aristida adoensis Community

Fuzzy k-means cluster number: M36
UPGMA, local cut information level: 99 %
Plots: 14_{NG}, 15_{NG}, 19_{NG}
Locations: Nyungwe, Gisovu

M21	14_{NG}	15_{NG}	19_{NG}	17_{NG}
14_{NG}	0	0.09	0.15	0.54
15_{NG}		0	0.19	0.52
19_{NG}			0	0.55
17_{NG}				0

Table 3.15: Bray-Curtis dissimilarities between the samples discussed.

M21	14_{NG}	15_{NG}	19_{NG}	17_{NG}
14_{NG}	0	0.02	0.09	0.9
15_{NG}		0	0.08	0.9
19_{NG}			0	0.85
17_{NG}				0

Table 3.16: Geographic distances between the samples discused in km.

The three plots at the foot of Mt. Muzimu exhibit the least dissimilarities only a few metres apart. All three contain *Faurea saligna* in minor abundances in the otherwise *Erica mannii* dominated tree stratum. *Olinia rochetiana* can also be found in two (15_{NG}, 19_{NG}) of the plots. *Morella serrata* appears in plots 14_{NG} and 15_{NG}. Within the herb layer, *Aristida adoensis* occurs within all three plots, almost ubiquitously. Additionally, in all three plots and only found on exposed rock at higher altitudes, an unidentified *Lichen* species has been collected. *Hedythyrsus thamnoideus* (14_{NG}, 15_{NG}) is found in two plots in the herb layer, as well as a not yet determined member of the *Urticaceae*.

All plots are situated around 2600 m a.s.l. The exposition ranges between NNW and NE via ENE. The depth of the sandy soils is at the shallow end of the spectrum at 0.41, 0.55 and 0.38 metres, respectively. Although the temperature could not be determined, soil samples could be drawn and measured for pH, which varies between 3.36 and 3.55. Only in one case (14_{NG}) is more than one tree layer present. Moreover, canopy height does not exceed 9 m. In all cases, the shrub layer is not well developed while the herb layer covers between 76% and 97% of the sites.

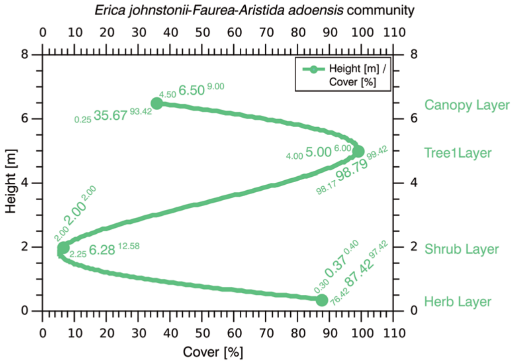

Figure 3.18: Cover-Height relation of the community recovered at Gisovu; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Species composition of the plots allows for a classification into Habiyaremye's (1997) *Ericetum johnstonii* (s.a.), placing the sites closer to plot 17_{NG}, which has been discussed above. On this matter, it has to be mentioned that plot 17_{NG} contains less species than the other plots. A sophisticated guess towards the reasons would find the more developed shrub layer to be the main cause for the fewer comprehensive herb layer in plot 17_{NG}.[1]

It is also here where a main difference can be found; the presence of *Erica kingaensis*. Consequently, it might be necessary to differentiate the association further. In order not to force the Braun-Blanquet System onto the Afromontane vegetation, two communities might replace the classification: an *Erica mannii-Erica kingaensis-Aristida adoensis* community and an *Erica mannii- (Faurea)-Aristida adoensis* community. The first community, albeit representing the manifestation of the construed vegetation unit on Mt. Muzimu, would correspond to Fischer and Killmann's (2008) Ericaceous shrub. This differentiation would also make a presently concealed morphological trait more conspicuous. While in plot 14_{NG} the canopy layer still reaches a height of 9 m, it decreases to 6 m (plot15_{NG}), 4.5 m (plot 19_{NG}) and, in the end, to 2.5 m in plot 17_{NG}. At the same time, the altitude increases from 2580 m to 2756 m a. s. l. Seemingly, the crown height is related to altitude.[2] With an R^2 of 0.751, a linear regression supports the presumption. With all the caveats necessary, the different species composition and the undoubtedly differing morphology of the stands make a differentiation into two communities seem reasonable. Both FCM-NC and UPGMA find the same cluster, with a local cut at the 99% information level for UPGMA.

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[1] The author is well aware that a multitude of factors impacts species composition and does not claim that the increased shade is the only parameter, hence, this is a sophisticated guess.

[2] This is an illustrative example for the plurality of parameters exerting influence on the vegetation. It does not demonstrate a conclusive proof. Further scrutiny is given in chapter 4.

Table 3.17: *Erica mannii-Aristida adoensis* community
Erica mannii-Faurea-Aristida adoensis community

Sample Site / Species	^{14}NG	^{15}NG	^{19}NG
Exposition	NNW	NE	ENE
Inclination [°]	15	15	29
Position / Relief	HM	HM	HO
Precipitation / a [mm]	1626	1626	1626
Elevation a.s.l. [m]	2575	2578	2610
T S_{60} [°C]	n/a	n/a	n/a
pH	3.51	3.36	3.55
Soil texture	Su	Su	Sl
t Height [m]	9	6	4.5
t1 Height [m]	6	n/a	n/a
t2 Height [m]	n/a	n/a	n/a
t3 Height [m]	n/a	n/a	n/a
Shrub Height [m]	2	2	2
Herb Height [m]	0.3	0.4	0.4
Moss Height [m]	0.05	0.02	0.04
Juvenil Height [m]	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	0
Vegetation Cover [Londo]	10	10	10
t Cover [%]	0.25	13.33	93.42
t1 Cover [%]	99.42	98.17	0
t2 Cover [%]	0	0	0
t3 Cover [%]	0	0	0
Shrub Cover [%]	2.25	4	12.58
Herb Cover [%]	88.42	76.42	97.42
Moss Cover [%]	n/a	n/a	n/a
Juvenil Cover [Londo]	n/a	p4	p1
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a
Erica mannii	10	10	9
Aristida adoensis	8	7	10
Faurea saligna	p4	p2	0.7
Panicum sp.	m2	p1	p1
Olinia rochetiana		r1	p2
Myrica salicifolia	r1	0.7	
Pyrrhobryum spiniforme	r1	r1	
Asplenium sp. IV	p1	p1	
Hedythyrsus thamnoideus	p2	p2	
Otiophora pauciflora ssp. burttii	p1		
Rubus cf. steudneri	p2		
Asplenium cf. mildbraedii	p1		
cf. Senecio mariettae	r1		
cf. Asplenium mildbraedii	p1		
Carex spicatopaniculata	r1		
Acalypha sp. II	p1		
Senecio sp. V	r1		
Ipomoea involucrata	p1		
Pteridium aquilinum	p1		
Maytenus acuminata	r1		
Clematis simensis	p1		
Eragrostis mollior	r1		
Pinus cf. caribaea	r1		
Asplenium mildbraedii		p1	

Table 3.17: *Erica mannii-Aristida adoensis* community
Erica mannii-Faurea-Aristida adoensis community (continued)

Sample Site / Species	14_{NG}	15_{NG}	19_{NG}
cf. Ardisiandra wettsteinii		p1	
Pleopeltis macrocarpa		r1	
Polygala ruwenzoriensis		p1	
Solanecio mannii		r1	
Carex cf. conferta		p1	
Pinus patula		0.7	
Panicum sp. I		p1	
Rubus sp. IV		p1	
Kotschya aeschynomenoides			r1
Agarista salicifolia			p2
Senecio subsessilis			r1
Conyza welwitschii			r1
Conyza sp. I			r1
Senecio maranguensis			r1
Hypnum cupressiforme			r1
Campylopus sp.			r1
Hypericum revolutum			p4

Further species in the samples: **14_{NG}** : Urticaceae sp. p2; cf. Asteraceae sp. r1; Urticaceae sp. I r1; Polypodiales sp. XVIII r1; Lichen sp. p1; **15_{NG}** : Urticaceae sp. p1; Bryopsida sp. VI p2; Lichen sp. r1; Lichen sp. I p1; **19_{NG}**: Poaceae sp. II p1; Poaceae sp. I p1; Lichen sp. r1

3.2.11 *Erica mannii-Microlepia speluncae-Breutelia diffracta* Edaphic Community

Fuzzy k-means cluster number: M26
UPGMA, local cut information level: 34 %
Plot: 78_{NGk} Locations: Nyungwe, Gisakura

M26	14_{NG}	15_{NG}	17_{NG}	19_{NG}	28_{NB}	78_{NGk}
14_{NG}	0	0.09	0.54	0.15	0.48	0.91
15_{NG}		0	0.52	0.19	0.48	0.92
17_{NG}			0	0.55	0.49	0.84
19_{NG}				0	0.53	0.92
28_{NB}					0	0.68
78_{NGk}						0

Table 3.18: Bray-Curtis dissimilarities between the samples discussed.

M26	14_{NG}	15_{NG}	17_{NG}	19_{NG}	28_{NB}	78_{NGk}
14_{NG}	0	0.02	0.9	0.09	15.34	27.79
15_{NG}		0	0.9	0.08	15.35	27.79
17_{NG}			0	0.85	14.46	26.94
19_{NG}				0	15.31	27.72
28_{NB}					0	16.51
78_{NGk}						0

Table 3.19: Geographic distances between the samples discused in km.

The plot located at Gisakura poses some difficulties of its own in terms of classification. Within the site, *Erica mannii* has its lowest altitudinal occurrence throughout the survey. Despite this, the canopy layer of the plot is quite open, i.e., though dominated by *E. mannii*, this dominance is asserted by a total ground cover of only ∼13%. Only *E. mannii*, *Maytenus acuminata*, *Otiophora pauciflora ssp. burtii* and *Breutelia diffracta* connect plot 28_{NB} on Mt. Bigugu to the plot at hand. Plot 28_{NB} and plot 17_{NG} are the most similar samples to 78_{NGk} according to the UPGMA result. Yet, a combination will not be made. Almost 70% dissimilarity, a highly differing stand characteristic and the much lower canopy height provide the rationale for the decision. In addtion, FCM-NC set the sample apart in a cliuster of its own. The ENE facing site is situated at an altitudinal level of 2004 m a.s.l. The drillable soil depth of 0.36 m prevents the measuring of the temperature while the measurement of the pH is possible and amounts to 3.31 of the sandy soil. The canopy of the tallest of the two tree layers reaches 4 metres and also covers a herb, a shrub and moss layer that, except for the herb layer, are not well developed.

Sabicea bequaertii, an Albertine Rift endemic (Habiyaremye, 1997, p. 195), does not lend itself to a classification of the stand encountered at Gisakura. The most abundant species, the pantropical fern *Microlepia speluncae* and the moss *Breutelia diffracta*, are not suitable namesakes either. This situation leaves no choice but to seek for a classification modelled along *Erica mannii*, *Maytenus acuminata* and all other species occurring in small to minor abundances.

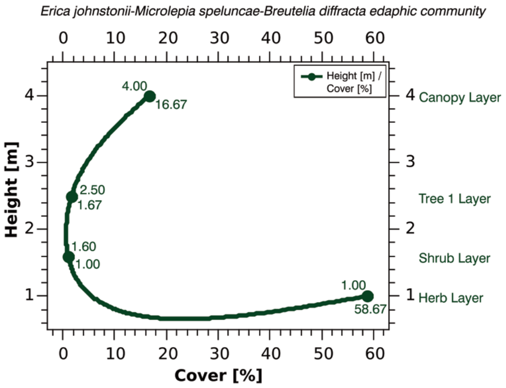

Figure 3.19: Cover-Height relation of the community recovered at Gisakura; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Despite the altitude which should give a hint to the vegetation of the lower-level montane cloud forest, the community encountered seems to represent the upper montane forest. Although a bit vague, since Lebrun & Gilbert (1954) never cited *Erica mannii* to occur within the Oleo-Jasminetalia or the Agaurio-Myricion, the author of this research follows Fischer (1996) and Habiyaremye (1997), respectively, and places the community accordingly. Lebrun & Gilbert (1954) facilitated this ruling with their statements on pages 31 and 32, respectively: "*Ces forêts occupent, à plus haute altitude, de 1.500 à 3.200 m environ, des sols généralement très drainés ou superficiels* […] *ou se rencontrent, sur des substrats variés, dans les étages de végétation à caractère franchement montagnard, dans des conditions climato-édaphiques entraînant une évidente xérophilie*"; and further: "*Beaucoup de ces groupements sont des stades syngénétiques progressifs aboutissant à des groupements presque paraclimax, liés à des sols immatures ou à drainage excessif, et dont l'évolution vers des formes forestières plus mésophiles est extrêmement lente. D'autres sont des formations régressives correspondant à la dégradation d'une forêt qui peut d'ailleurs appartenir au même type fondamental.*"

Despite *M. speluncae* being present and, thus, indicating moist conditions, the shallow well-drained soil on an upper slope corresponds to the required conditions depicted by Lebrun & Gilbert (1954). Deciding whether the state of the sample at hand is progressive or regressive is not effortless. The available satellite imagery does not reveal any signs of landslides or fires in the past. The slow development into the surrounding forest type (cf. cluster M27) also implies that this is seemingly the paraclimactic state mentioned by Lebrun & Gilbert (1954). The site might be the only true outlier, at least for the lower montane level. A preliminary community name could be: *Erica mannii-Microlepia speluncae-Breutelia diffracta* edaphic community.

Table 3.20: *Erica mannii-Microlepia speluncae-Breutelia diffracta* Edaphic Community

Sample Site / Species	28_{NB}	17_{NG}	78_{NGk}
Exposition	ENE	NE	ENE
Inclination [°]	31	10	n/a
Position / Relief	HO	HO	HO
Precipitation / a [mm]	1808	1643	2924
Elevation a.s.l. [m]	2772	2751	2004
T S_{60} [°C]	n/a	n/a	n/a
pH	2.88	3.56	3.31
Soil texture	Sl	Sl	Su
t Height [m]	9	2.5	4
t1 Height [m]	4	n/a	2.5
t2 Height [m]	n/a	n/a	n
t3 Height [m]	n/a	n/a	n
Shrub Height [m]	2.5	1.1	1.6
Herb Height [m]	1	0.3	1
Moss Height [m]	0.05	0.02	0.05
Juvenil Height [m]	n/a	n/a	n/a
Epiphyts [m/6m]	1	0	0
Vegetation Cover [Londo]	10	10	10
t Cover [%]	92.08	53.17	16.67
t1 Cover [%]	0.67	0	1.67
t2 Cover [%]	0	0	0
t3 Cover [%]	0	0	0
Shrub Cover [%]	11.08	44.58	1
Herb Cover [%]	52.83	88.92	58.67
Moss Cover [%]	n/a	n/a	n/a
Juvenil Cover [Londo]	n/a	p1	p1
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a
Erica mannii	9	6	1.2
Maytenus acuminata	0.7		p2
Breutelia diffracta	3		3
Otiophora pauciflora ssp. burttii	0.7	r1	p1
Scleria distans		p1	p1
Adenochloa adenophora		p1	m1
Asplenium friesiorum	1.2		
Senecio sp. IV	0.7		
Podocarpus latifolius	p2		
Asplenium mildbraedii	p1		
Myrsine melanophloeos	p4		
Phyllanthus nummularifolius	p1		
Maesa lanceolata	p2		
Rubus cf. steudneri	p2		
Hedythyrsus thamnoideus	p2		
Mikania cordata	r1		
Tacazzea apiculata	p1		
Senecio mariettae	p1		
Asplenium sp. IV	p1		
Asplenium sp. XXII	p1		
Cyperus sp. I	r1		
Polypodiales sp. XV	r1		
Asplenium sp. XX	p2		
Hydrocotyle sp.	p1		
Centella asiatica	p1		

Table 3.20: *Erica mannii-Microlepia speluncae-Breutelia diffracta* Edaphic Community

Sample Site / Species	28_{NB}	17_{NG}	78_{NGk}
Elaphoglossum cf. rwandense	p2		
Afroligusticum runssoricum	m4		
cf. Aristida adoensis		9	
Erica kingaensis		4	
Faurea saligna		r1	
Struthiola thomsonii		p1	
Kotschya aeschynomenoides		r1	
Campylopus sp.		p2	
Pyrrhobryum spiniforme		p1	
Sporobolus sp.		p1	
Microlepia speluncae			5-
Sabicea bequaertii			0.7
Syzygium parvifolium			p1
Pteridium aquilinum			p2
Nuxia congesta			p2
Senecio maranguensis			p1
Virectaria major			m2
Smilax anceps			p2
Hymenodictyon floribundum			p1
Arthropteris cf. monocarpa			p1
Secamone racemosa			p2
Vernonia scaettae			p1
cf. Pilea johnstonii			m1
Bothriocline cf. nyungwensis			p1
Nephrolepis undulata			r1

Further species in the samples: **28_{NB}:** Polypodiales sp. XX 0,7; Poaceae sp. VII p1; **17_{NG}:** Poaceae sp. III r1; Poaceae sp. IV r1; Bryopsida sp. VIII p4; **78_{NGk}:** Poaceae sp. VIII p1; Poaceae sp. IX m1; Lichen sp. I p2

3.2.12 *Podocarpus latifolius-Myrsine-Mimulopsis excellens-Isoglossa vulcanicola* Community

Fuzzy k-means cluster number: M31, Noise 27_{NB}
UPGMA, local cut information level: 91 %, 60 % incl. 27_{NB}
Plots: 26_{NB}, 29_{NB}, 31_{NB}, 27_{NB} Locations: Nyungwe, Mt. Bigugu

M31	26_{NB}	29_{NB}	31_{NB}	27_{NB}
26_{NB}	0	0.39	0.46	0.64
29_{NB}		0	0.5	0.65
31_{NB}			0	0.57
27_{NB}				0

Table 3.21: Bray-Curtis dissimilarities between the samples discussed.

M31	26_{NB}	29_{NB}	31_{NB}	27_{NB}
26_{NB}	0	0.07	0.21	0.19
29_{NB}		0	0.28	0.25
31_{NB}			0	0.05
27_{NB}				0

Table 3.22: Geographic distances between the samples discused in km.

Towards the summit region of Mount Bigugu, between 2724 and 2774 m a. s. l., *Syzygium parvifolium* recedes and gives way to *Gymnosporia acuminata*, *Maesa lanceolata* and *Apodytes dimidiata*. *Myrsine melanophloeos* and *Psychotria mahonii* are still present, while *Podocarpus latifolius* expands its dominance. *Syzygium parvifolium* can still be found in plots 31_{NB}, 26_{NB} and 27_{NB}. It is also in these three samples where *Psychotria mahonii* can be found in several vegetation layers from the shrub via the third and second tree layer to the canopy. Here *Myrsine melanophloeos*, in little abundances though, can be found in all four plots. *Apodytes dimidiata* is shared by three plots with varying abundances throughout the strata, starting in the shrub layer with the highest abundance in plot 29_{NB} in the second tallest and the tallest tree layer. *Gymnosporia* occurs in plot 29_{NB} as well and is also present in site 26_{NB}, with the main abundance in the second tree layer. *Lobelia petiolata* is a species both plots also have in common. In both, the species can be found in several layers starting in the shrub stratum and reaching its highest abundance values in the second tree layer of plot 29_{NB}. *Galiniera saxifraga* can be found in most plots within the shrub layer and the second tree layer and in two plots also in the third tree layer. *Rytigynia kigeziensis* appears in all four plots within the shrub layer with only low abundances. The herb layer of all four plots comprises *Asplenium mildbraedii* in minor abundances, and most of the herb layer of the sampling plots is occupied by *Mimulopsis excellens*. Where there is space left by *M. excellens*, *Isoglossa vucanicola* is found in all plots. Plot 27_{NB}, which has been placed in the noise cluster by FCM-NC, was joined with the other plots with some hesitation. Mostly the occurrence of *Ilex mitis*, the lower abundance of *M. excellens*, the occurrence of *Begonia meyeri-johannis* and the slightly altered abundance proportions of several species, has led to the segregation of the otherwise spatially close plot. Since *I. mitis* has not been observed to constitute a community under its prevalence and although it is as abundant as *P. latifolius*, the latter species is used for categorisation. Despite the somewhat elevated Bray-Curtis values and the differences in species composition, the site fits the community description.

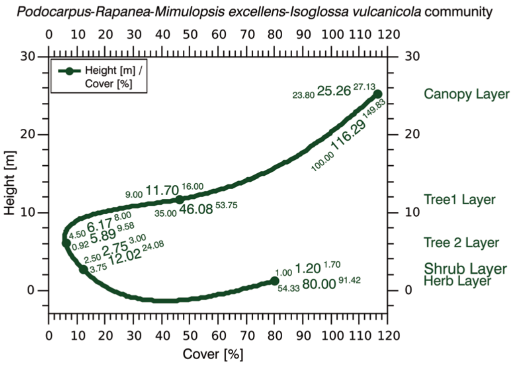

Figure 3.20: Cover-Height relation of the community recovered at Gisakura; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

At a glimpse, species composition reveals quite a number of similarities to cluster M7. The main difference here is the presence of *Erica mannii* and the differing vertical stratification at the sites constituting said cluster (see 3.2.11).

With no preferences in exposition, the sites can be found in the upper level of the montane rain forest on shallow sandy to loamy and silty soils. The pH values range between 2.61 and 2.80 while the temperature, where it can be measured, does not exceed 12.30°C. Most of the sites sustain three tree layers with a canopy not exceeding 27 m. Shrub cover reaches, at most, medium values, while the herb layer is well developed.

Fischer (1996) stated that within the Kahuzi-Biega National Park (Zaire now D.R.C.), the upper cloud forest was dominated by *Podocarpus* forests, which seems to be valid for the Nyungwe National Park as well. According to Habiyaremye (1997) and Lebrun & Gilbert (1954) the community encountered contains species from the order Ficalhoo-Podocarpetalia and Polyscietalia-Fulvae Lebrun & Gilbert (1954) as well. *Maesa lanceolata* and *R. melanophloeos* are to be assigned to this order. *Gymnosporia acuminata* has so far only been found up to 2450 m a. s. l. (Bloesch, 2009). Lebrun & Gilbert (1954) placed the species within the order Oleo-Jasminetalia. *Apodytes dimidiata* has also only been described to occur up to 2500 m a. s. l. None of the literature surveyed placed the species into a community. With *Ilex mitis*, a species from the order Agaurio-Myricion Lebrun & Gilbert (1954), is joining the intermixture. Though the character of the remaining stands does not correspond with the Agaurio-Myricion, the ecological conditions at the sites do. Thus, a member of the "Les forêts sclérophylles montagnardes […]" and from the "Alliance montagnarde […]" (LEBRUN & GILBERT 1954, pp.31-32) may very well be encountered here.

Maesa lanceolata may give a hint on the secondary character of this part of the forest. LEBRUN & GILBERT (1954) assigned this species to the order Polyscietalia-Fulvae. The presence of *Begonia meyeri-johannis* also points to secondary vegetation. (cf. FISCHER & KILLMANN, 2008). An adequate description of the plant assembly found would be the *Podocarpus latifolius*-*Myrsine melanophloeos*-*Mimulopsis excellens*-(Isoglossa vulcanicola) community.

With a local cut at ca. the 91% information level, three of the plots are quite closely related according to the UPGMA result. At the given parameters, the fuzzy c-means delivers the same result. Taking the Bray-Curtis indices into account, the result has to be taken with some caution, 39% to 50% dissimilarity does not constitute a reliable grouping. Lowering the information level to 60 % and increasing the dissimilarities to 65%, the inclusion of plot 27_{NB} further weakens the relational structure. However, under the given circumstances and until further data are available, a coherent picture of the montane vegetation communities, as they can be found here, emerges.

Table 3.23: *Podocarpus latifolius-Mimulopsis excellens-Isoglossa vulcanicola* community

Sample Site / Species	26_{NB}	29_{NB}	31_{NB}	27_{NB}
Exposition	SSE	NNW	ESE	WSW
Inclination [°]	10	12	16	31
Position / Relief	HM	HO	HM	HO
Precipitation / a [mm]	1808	1808	1808	1808
Elevation a.s.l. [m]	2774	2771	2724	2731
$T\ S_{60}$ [°C]	n/a	12.30	11.10	n/a
pH	2.80	2.71	2.61	2.61
Soil texture	Sl	Sl	Lts	Us
t Height [m]	27.13	24	23.8	26.1
t1 Height [m]	9	11.79	16	10
t2 Height [m]	6	n/a	8	4.5
t3 Height [m]	n/a	n/a	n/a	n/a
Shrub Height [m]	3	2.5	3	2.50
Herb Height [m]	1	1.1	1.7	1
Moss Height [m]	0.02	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	0	1	1	1
Vegetation Cover [Londo]	10	10	10	10
t Cover [%]	104.17	111.17	149.83	100.00
t1 Cover [%]	47.42	48.17	53.75	35.50
t2 Cover [%]	7.17	0	9.58	0.92
t3 Cover [%]	0	0	0	0
Shrub Cover [%]	13.58	3.75	6.67	24.08
Herb Cover [%]	91.42	84	90.25	54.33
Moss Cover [%]	0.01	0	0	0
Juvenil Cover [Londo]	p2	p2	n/a	p1
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	n/a
Podocarpus latifolius	10	8	6	4
Mimulopsis excellens	5+	7	8	3
Isoglossa vulcanicola	4	p4	p2	p2
Myrsine melanophloeos	0.7	r2	2	r1
Rytigynia kigeziensis	p2	p1	r1	p2
Galiniera saxifraga	p2	p2	3	p2
Asplenium mildbraedii	p2	p1	p1	p1
Apodytes dimidiata	p2	3	r1	
Psychotria mahonii	3		5-	p2
Syzygium parvifolium	p2		4	3
Asplenium sp. IV	p1		p1	p1
Asparagus asparagoides	r1	r1		m1
Mikaniopsis tedliei		p1	p2	p1
Olinia rochetiana		r2	3	p2
Keetia gueinzii		p1	r1	p2
Blotiella glabra		p1	p2	p4
Clutia abyssinica	p2	r1		
Maytenus acuminata	0.7	0.7		
Lobelia petiolata	p4	4		
Dryopteris sp. XII		p4	p1	
Pilea johnstonii	r1			0.7
Coleus autranii		r1		p2
Impatiens gesneroidea			r1	p1
Allophylus chaunostachys			r1	p2
Xymalos monospora			p1	0.7

Table 3.23: *Podocarpus latifolius-Mimulopsis excellens-Isoglossa vulcanicola* community (continued)

Sample Site / Species	26_{NB}	29_{NB}	31_{NB}	27_{NB}
Gynura scandens	p1			
Aneilema aequinoctiale	p1			
Asplenium friesiorum	p1			
Racopilum africanum	p1			
Asplenium sp. VII	p2			
Dryopteris sp. V	0.7			
Cyperaceae sp. III	r1			
Bryopsida sp. XI	r1			
Olea capensis ssp. hochstetteri		p2		
Asplenium sp. XXII		p1		
Asplenium sp. XX		p1		
Elaphoglossum cf. rwandense		r1		
cf. Olea capensis ssp. hochstetteri		r1		
Asplenium sp. XXXV		p2		
Blotiella trichosora		r1		
Cyperaceae sp. II		p1		
Mikania cordata			p1	
Asplenium sp. VI			p1	
Dryopteris sp. IX			p1	
Asplenium protensum			r1	
Ilex mitis				4
Astropanax goetzenii				2
Begonia meyeri-johannis				1.2
Urera hypselodendron				r1
Embelia libeniana				r1
Coleus maculosus subsp. edulis				p1
Pilea rivularis				p2
Pilotrichella ampullacea				r1
Asplenium sp. II				p1
Dryopteris sp. II				p1
Asplenium sp. XV				p2
Kalanchoe sp.				p2
Asplenium sp. VIII				r1
Polypodiales sp. IV				p1
Pteris sp. I				p1
Asplenium sp. IX				p2
Cyperaceae sp. IV				p2

Further species in the samples:**26_{NB}** : Bryopsida sp. XI r1; **29_{NB}**: Cyperaceae sp. II p1

3.2.13 *Isache mauritiana-Maesa lanceolata-Xymalos monospora* Community

Fuzzy k-means cluster number: M10
UPGMA, local cut information level: 92 %
Plots: 82_{Gw}, 90_{Gw}

Locations: Nyungwe, Gahurizo; Gishwati Forest

M10	34_{NGa}	82_{Gw}	90_{Gw}
34_{NGa}	0	0.34	0.56
82_{Gw}		0	0.35
90_{Gw}			0

Table 3.24: Bray-Curtis dissimilarities between the samples discussed.

M10	34_{NGa}	82_{Gw}	90_{Gw}
34_{NGa}	0	93.99	94.62
82_{Gw}		0	0.63
90_{Gw}			0

Table 3.25: Geographic distances between the samples discussed in km.

About 94 km apart, Nyungwe Forest around the ranger station at Gahurizo and Gishwati forest show some similarities. About 66% resemblance between plot 34_{NGa} and 82_{Gw} are brought about by the presence of *Macaranga kilimandscharica* as the dominant tree species and by the predominance of *Isachne mauritiana* in the herb stratum. *I. mauritiana* also connects plot 90_{Gw} to both sites mentioned, and *Maesa lanceolata* is a further connecting species between the three plots. In plot 82_{Gw}, *Maesa lanceolata* is present in high abundance, thus connecting plot 90_{Gw}, with an equal abundance, closer to the cluster obtained through the fuzzy c-means. Next to a couple of species in minor abundances, *Xymalos monospora* (present in moderate abundance) increases the similarity between both Gishwati sites. Among a number of species throughout all strata, whose abundances are at most to be described with paululum, *Dombeya torrida* also only occurs in plot 90_{Gw}. The incidence of *Dombeya torrida* in the crown layer of the site is a harbinger of the dominance of the species within the adjacent plots. In sample site 90_{Gw}, the species is sharing the dominance within the crown layer with *M. lanceolata* to almost equal parts; thus, setting plot 90_{Gw} a bit further apart from the other sites. This consequential higher dissimilarity can also be observed in the UPGMA derived dendrogram, placing plots 34_{NGa} and 82_{Gw} closer together than both to plot 90_{Gw}. A local cut at about the 92% information level would give a cluster similar to the FCM-NC result.

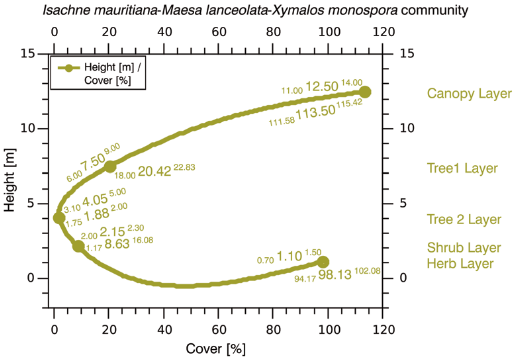

Figure 3.21: Cover-Height relation of the community recovered in Gishwati Forest; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

The sites are facing N and NNE respectively while being situated around 2100 m a.s.l. The drillable soil depth is at the lower end of the spectrum and reaches a maximum of 0.76 m in plot 82_{Gw}. In both cases, the temperature of the soil at a depth of 0.60 m reaches 15.50°C. The sandy soil in plot 82_{Gw} holds a pH of 3.79, and the silty soil of site 90_{Gw} a pH of 4.04. In both sites, three tree layers can be observed with a canopy height of 14 m maximally. The shrub layer is sparsely developed while the herb layer covers all of the ground in both plots.

Fischer & Hinkel (1994) described low-stemmed *Macaranga kilimandscharica* secondary forests for Gishwati. The vegetation found allows for placement of the cluster in proximity to this community. However, low-stemmed does not fit plot 34_{NGa}. Lebrun & Gilbert (1954) placed *Macaranga* into the alliance *Polyscion fulvae*. This secondary character is underlined, among others, by *Maesa lanceolata*, *Xymalos monospora* and *Myrianthus holstii*. A *Maesa lanceolata-Isachne mauritiana-Macaranga kilimandscharica* community would depict the vegetation character adequately. Here, at least one fact would be omitted; the already mentioned height of the canopy. Additionally, species number in the plot at Gahurizo is much lower than within the other plots. This certainly is not a reason for regrouping in itself but leaves a certain doubt about a joint classification. Within a variety of options, all of which are contestable, and under the unyielding condition of tentativeness, it seems the least arbitrary to combine the Gishwati plots and set the Gahurizo plot aside. Ignoring the elevated abundances of *Macaranga* and *Dombeya* in the Gishwati plots respectively, the community, which could be subsumed under low-stemmed secondary forests, might be called the *Isachne mauritiana-Maesa lanceolata-Xymalos monospora* community. The plot at Gahurizo could be incorporated into HABIYAREMYE's (1997) *Macarango psychotrietum*. The idea of a *Maesa lanceolata-Isachne mauritiana-Macaranga kilimandscharica* vegetation unit might be more adequately employed in a modified form within a syn-sociological context.

Table 3.26: *Isache mauritiana-Maesa lanceolata-Xymalos monospora* community

Sample Site / Species	34_{NGa}	82_{Gw}	90_{Gw}
Exposition	E	NNE	N
Inclination [°]	30	29	30
Position / Relief	HO	HM	HM
Precipitation / a [mm]	1675	1378	1376
Elevation a.s.l. [m]	2512	2119	2115
T S_{60} [°C]	14.5	15.50	15.50
pH	3.15	3.79	4.04
Soil texture	Sl	Sl	Us
t Height [m]	20.94	11	14
t1 Height [m]	6	6	9
t2 Height [m]	n/a	3.1	5
t3 Height [m]	n/a	n/a	n/a
Shrub Height [m]	2.3	2	2.3
Herb Height [m]	1	1.5	0.7
Moss Height [m]	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1
Vegetation Cover [Londo]	10	10	10
t Cover [%]	97.5	115.42	111.58
t1 Cover [%]	11.08	22.83	18
t2 Cover [%]	0	2	1.75
t3 Cover [%]	0	0	0
Shrub Cover [%]	2.5	16.08	1.17
Herb Cover [%]	101.67	94.17	102.08
Moss Cover [%]	n/a	n/a	n/a
Juvenil Cover [Londo]	p1	p1	a1
Juvenil Shrub Cover [Londo]	n/a	p1	a1
Syzygium parvifolium	r1	r1	r1
Maesa lanceolata	1.2	5+	5+
Isachne mauritiana	9	9	9
Macaranga kilimandscharica	10	6	
Myrsine melanophloeos	r1	p2	
Chassalia subochreata	r1	p1	
Psychotria mahonii	p1	p2	
Xymalos monospora		3	2
Carapa grandiflora		p1	p1
Mimulopsis solmsii		p2	p1
Myrianthus holstii		r2	p2
Asplenium cf. friesiorum		p2	p1
Urera hypselodendron		p4	p1
Asplenium friesiorum	m4		p2

Table 3.26: *Isache mauritiana-Maesa lanceolata-Xymalos monospora* community (continued)

Sample Site / Species	34NGa	82Gw	90Gw
Clerodendrum sp.		r1	1.2
Begonia meyeri-johannis	m2		
Allophylus chaunostachys	r1		
Galiniera saxifraga	p2		
Olinia rochetiana	r1		
Drymaria cf. cordata	m1		
Sericostachys scandens	p4		
Asplenium mildbraedii	m2		
Ipomoea involucrata	r1		
Rubus cf. steudneri	p1		
Rubus cf. apetalus	p2		
Dryopteris sp. XII	r1		
cf. Asplenium friesiorum	p2		
Pycnostachys meyeri	r1		
Rytigynia sp. IV	p1		
Dichanthelium hillebrandianum	p1		
Asplenium sandersonii		m1	
Dryopteris cf. schimperiana		p1	
Impatiens purpureo-violacea		p4	
Pteridium aquilinum		r1	
Polyscias fulva		r1	
Neoboutonia macrocalyx		r1	
Coleus melleri		p1	
Rourea thomsonii		r1	
Asplenium cf. mildbraedii		r1	
Psychotria peduncularis		p2	
Rubus cf. pinnatus		r1	
Asplenium cf. mannii		m1	
Cucurbitaceae sp. XVII		r1	
Drymaria sp.		m1	
Cucurbitaceae sp. XII		p1	
Ipomoea sp.		r1	
Vernonia sp. III		p1	
Vernonia sp. I		p1	
Dryopteris sp. VII		p1	
cf. Oxyanthus sp.		r1	
Harungana cf. montana		p1	
Ficus sp.		r1	
Dombeya torrida			5-
cf. Justicia sp. I			0.7
Vernonia sp. IV			p1
Momordica sp.			p1

Further species in the samples: **34_{NGa}**: Caryophyllaceae sp. I r1; **82_{Gw}**: Cyperaceae sp. p1; Gen. indet. spec. indet. CLXXXIV p1; Gen. indet. spec. indet. CLXXXVII p1; Lamiaceae sp. p1; Gen. indet. spec. indet. CXC p1; Gen. indet. spec. indet. CXCI r1; Gen. indet. spec. indet. LXXXVII r1; Lilianae sp. r1; **90_{Gw}**: Cucurbitaceae sp. XVIII p1; Cucurbitaceae sp. XIX p1; Woodsiaceae sp. V r1; Cucurbitaceae sp. VII r1; Asteraceae sp. VI p1; Rubiaceae sp. XVII r1; Gen. indet. spec. indet. XLVII r1; Gen. indet. spec. indet. LIV r1

3.2.14 Syzygium parvifolium-Macaranga kilimandscharica Community

Fuzzy k-means cluster number: M11, M13, M32
UPGMA, local cut information level: 74 %
Plots: 2_{NU}, 3_{NU}, 4_{NU}, 8_{NU}, 79_{NGk}
Locations: Nyungwe, Uwinka, Gisakura

M11 / M32 / M13	2_{NU}	3_{NU}	4_{NU}	8_{NU}	79_{NGk}
2_{NU}	0	0.62	0.5	0.62	0.68
3_{NU}		0	0.71	0.78	0.82
4_{NU}			0	0.58	0.56
8_{NU}				0	0.47
79_{NGk}					0

Table 3.27: Bray-Curtis dissimilarities between the samples discussed.

M11 / M13 / M32	2_{NU}	3_{NU}	4_{NU}	8_{NU}	79_{NGk}
2_{NU}	0	0.18	0.35	0.35	11.11
3_{NU}		0	0.17	0.52	10.97
4_{NU}			0	0.69	10.83
8_{NU}				0	11.45
79_{NGk}					0

Table 3.28: Geographic distances between the samples discused in km.

Cutting the dendrogram obtained by UPGMA locally at the 74 % information level would reveal a cluster not found as such by the fuzzy c-means with noise clustering. In the cluster so derived, plots 8_{NU} and 79_{NGk} are more similar to each other than to plots 2_{NU} and 4_{NU} (see Fig. 3.6). Regarding plots 2_{NU} and 4_{NU}, the results stemming from FCM-NC differ strongly. Here, plots 3_{NU} and 2_{NU} have been grouped, and plot 4_{NU} composes a cluster of its own. The secondary membership computed by FCM-NC for plot 3_{NU} puts the site into the noise cluster. The plot in Nyungwe Forest around Uwinka is most similar to plot 2_{NU} (62% dissimilarity) followed by plot 20_{NG} (65 % dissimilarity) around Gisovu. Plot 20_{NG} has been allocated to a cluster only comprising the one site, which will be discussed at a later point. Plot 3_{NU} could be included in the community, the reason as to why will be discussed in the following, starting with substantiating why sites 2_{NU}, 4_{NU}, 8_{NU} and 79_{NGk} could be combined. Certainly, the high dissimilarity values of up to 68%, second the establishment of two clusters. Still, a closer look at species compositions and abundances opens up the possibility of combining clusters M11, M13 and M32 as well as of describing a conjoint community.

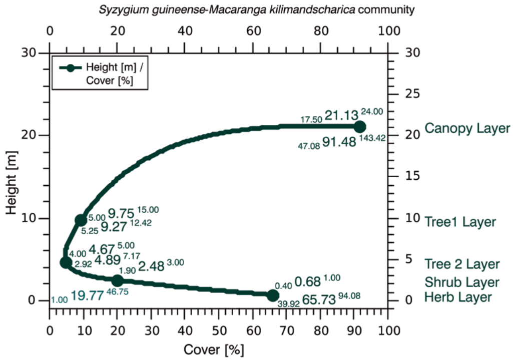

Figure 3.22: Cover-Height relation of the community recovered at Uwinka and Gisakura; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

With exposition all over the compass, all plots are situated at the medium level of the montane rain forest with the exemption of site 79_{NGk}, which can be found in the lower level. Soil texture varies from sandy to loamy and silty to clay. The drillable soil depth is in the midrange of the survey's spectrum, reaching a maximum of 1.47 m at site 3_{NU}. Soil temperature has a mean of 14.54°C, reaching its maximum at site 79_{NGk} with 17.00°C. The pH value ranges between 2.56 and 3.58.

With the exemption of sites 8_{NU} and 79_{NGk}, which hold three tree layers, all sites harbour two tree strata. The shrub layer is almost non-existent at sites 8_{NU} and 79_{NGk} and covers between 28% and 47% at the other sites. The herb layer reaches medium cover in most plots and exceeds 80% and 90% in sites 4_{NU} and 79_{NGk} respectively. The canopy height ranges between 15.50 and 24.00 metres.

Syzygium parvifolium is the prevailing species in the canopy layer at four of the sites, thus connecting Uwinka and the 12 km away Gisakura. *Chassalia subochreata,* though far less abundant, is found in all the stands. Mostly in the shrub layer but also found in the herb and third tree layer, *Allophylus chaunostachys* occurs in four plots in low abundances. *Psychotria mahonii*, present in only three stands, can be found in the same small amounts. Three sites at Uwinka (2_{NU}, 3_{NU}, 8_{NU}) and the site at Gisakura share *Macaranga kilimandscharica* which can be found, partly in moderate abundances, from the shrub layer upwards into the highest stratum. *Mikaniopsis tedliei* is also found twining through the herb, shrub, third and second tree layer (Uwinka) in the four sites. The three sites at Uwinka have *Begonia meyeri-johannis* in common; mostly to be found in the herb layer, it can also be seen in the shrub stratum. Another commonality between Uwinka and Gisakura is *Asplenium sandersonii*, which can be found in three plots in minor abundances. The plots at Uwinka exhibit further similarities, comprised of *Embelia libeniana*, *Sericostachys scandens* and *Isachne mauritiana*. Within plot 3_{NU}, *Carapa grandiflora* dominates the tree layer while *Syzygium parvifolium* recedes. Further similarities are mostly found within the herb layer. While the shrub, the second tree layer and the canopy exhibit further resemblance, plot three still exhibits an elevated dissimilarity to the other plots except for the shrub layer of plot 4_{NU}, which shows a heightened similarity. According to Bloesch et al. (2009, p. 354), *C. grandiflora* frequently occurs alongside *Syzygium parvifolium*. Although the subspecies could not be identified, a respective assumption may be allowed considering the not yet consolidated taxonomy of the species as well. Other considerations pertain to the very small plot size, the density distributions of tropical species and the stochastic components of species distribution. Thus, the accommodation of plot three into the community does not pose an insuperable obstacle. In conclusion, under the sampling regime at hand and on a strictly preliminary basis, inclusion of the plot into the *Syzygium parvifolium-Macaranga kilimandscharica* community established here will be undertaken at this point. In essence, though spatially close, further samples have to be drawn to conclusively concede or reject the inclusion of plot three within the cluster available. The small-scale patchiness of the vegetation is not amenable to a hard categorisation.

Classification into the existing system poses yet again quite a challenge. The class *Strombosio-Parinarietea* Lebrun & Gilbert (1954) is applicable, but from there no clear-cut allocation is possible. Commonalities with the *Macaranga-Syzygium-Podocarpus* secondary forest described by Fischer & Hinkel (1994) are few and therefore do not permit an assignment. Keeping the classification in a single cluster for the plots 8_{NU} and 79_{NGk} would not be sufficient to classify said vegetation into the community previously mentioned. due to the same reasoning, and the rationale given under 2.4 would add to the provisional character of the decision. The classification into the order *Ficalhoo-Podocarpetalia* by Habiyaremye (1997) could not be retraced within the original work of Lebrun & Gilbert (1954). Lebrun & Gilbert (ibid.) mentioned that *S. parvifolium* can occur in at least two syntaxonomic units. Of those units, neither the order Mitragyno-Raphietalia Schnell 1952 nor the order Ecastaphylla brownei Schnell 1952 is applicable for obvious reasons. A *Syzygium parvifolium-Macaranga kilimandscharica* community, seems to best encompass the vegetation found.

Table 3.29: *Syzygium parvifolium-Macaranga kilimandscharica* community

Sample Site / Species	^{2}NU	^{3}NU	^{4}NU	^{8}NU	^{79}NGk
Exposition	SE	E	NNW	ESE	ENE
Inclination [°]	8	0	17	26	28
Position / Relief	HO	KS	HO	HM	HO
Precipitation / a [mm]	1881	1881	1881	1876	2486
Elevation a.s.l. [m]	2500	2501	2513	2439	1876
T S_{60} [°C]	13.70	14.00	13.00	15.00	17.00
pH	2.73	2.71	2.56	2.69	3.58
Soil texture	Lt(s)	Ut	(T(l))	Ts	Sl
t Height [m]	17.5	15.5	20.5	24	22.5
t1 Height [m]	6	8	5	15	13
t2 Height [m]	n/a	n/a	n/a	5	5
t3 Height [m]	n/a	n/a	n/a	n/a	n/a
Shrub Height [m]	2.5	3.5	3	1.9	2.5
Herb Height [m]	0.7	0.6	0.6	1	0.4
Moss Height [m]	n/a	n/a	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	0	1	1	1	1
Vegetation Cover [Londo]	10	10	10	10	10
t Cover [%]	47.08	84.17	77.92	143.42	97.5
t1 Cover [%]	5.25	26.67	7	12.42	12.42
t2 Cover [%]	2.92	0	0	4.58	7.17
t3 Cover [%]	0	0	0	0	0
Shrub Cover [%]	29.17	28.33	46.75	2.17	1
Herb Cover [%]	39.92	46.75	84.58	44.33	94.08
Moss Cover [%]	n/a	n/a	n/a	n/a	n/a
Juvenil Cover [Londo]	4	4	2	p2	6
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	n/a	p1
Syzygium parvifolium	4	2	8	10	10
Chassalia subochreata	p4	2	2	p1	p1
Psychotria mahonii	p1	0.7	p1	r1	
Mikaniopsis tedliei	p2	1.2	p2	p4	
Embelia libeniana	p1	r1	p1	r2	
Isachne mauritiana	r1	p1	p1	r1	
Asplenium sandersonii	p1	p1	p1		p1
Macaranga kilimandscharica	1.2	1.2		3	p2
Allophylus chaunostachys	p1		p1	p2	p1
Carapa grandiflora		5-	p1		p2
Rytigynia kigeziensis	p4	p1	p4		
Asplenium erectum	p1	p1	p1		
Asplenium friesiorum	p1	p2	6		
Blotiella stipitata	p1	p1	p1		
Sericostachys scandens	r1		r1	1.2	

Table 3.29: *Syzygium parvifolium-Macaranga kilimandscharica* community (continued)

Sample Site / Species	^{2}NU	^{3}NU	^{4}NU	^{8}NU	^{79}NGk
Begonia meyeri-johannis	p1		r1	p1	
Mikania cordata	r1	p1		p2	
Oxyanthus troupinii	r1	r1		r1	
Astropanax goetzenii	p1	2			
Asplenium cf. gemmiferum	p1	r1			
Sericanthe leonardii	r1	r1			
Asplenium sp.	p1	p1			
Ocotea usambarensis	r4				r1
Asplenium cf. sandersonii	p1				p1
Urera hypselodendron	p1			p2	
Pilotrichella ampullacea	2		2		
Embelia schimperi	p1		r1		
Vittaria reekmansii		p1	r1		
Asplenium sp. II		p1	p2		
Casearia runssorica			r1		p1
Myrsine melanophloeos		r1			r1
Impatiens gesneroidea	p1				
Cassipourea ruwensorensis	r1				
Pavetta rwandensis	p1				
Clutia abyssinica	r1				
Galiniera saxifraga	p1				
Asplenium mildbraedii	r1				
Dryopteris sp. I	r1				
Asplenium mannii	r1				
Dryopteris cf. pentheri	r1				
Dryopteris cf. kilemensis	r1				
Pyrrhobryum spiniforme	r1				
Asplenium sp. I	p1				
Asplenium sp. III	r1				
Dryopteris sp. III	r1				
Asplenium aff. friesiorum	p1				
Asplenium sp. VI	p1				
Asplenium tenuicaudatum		r1			
Asplenium bugoiense		r1			
Balthasaria schliebenii		r1			
Myrsine cf. melanophloeos		r1			
Cyperus subgen. Mariscus		r1			
cf. Asplenium sp. XXVII		r1			
Asplenium linckii			r1		
Blotiella bouxiniana			p1		
Peperomia fernandopoiana			r1		
Stephania abyssinica			r1		

Table 3.29: *Syzygium parvifolium-Macaranga kilimandscharica* community (continued)

Sample Site / Species	2_{NU}	3_{NU}	4_{NU}	8_{NU}	79_{NGk}
Blotiella cf. stipitata			r1		
Asplenium aff. gemmiferum			r1		
Asplenium dregeanum			r1		
Asplenium cf. erectum			r1		
Dryopteris kilemensis			r1		
Asplenium sp. XV			p2		
Podocarpus latifolius				4	
Pteridium aquilinum				1.2	
Blotiella sp. II				0.7	
Beilschmiedia rwandensis				r1	
Mimulopsis solmsii				p1	
Momordica foetida				p1	
Polyscias fulva				p2	
Coccinia mildbraedii				r1	
Crassocephalum montuosum				r1	
Mikania sp.				r1	
Arthropteris cf. monocarpa					4
Pentadesma reyndersii					0.7
Clerodendrum johnstonii					r1
Apodytes dimidiata					r1
Virectaria major					p1
Asplenium sp. XIII					p1
Shirakiopsis elliptica					p4
Microcos mildbraedii					r1
Bridelia brideliifolia					r4
Albizia gummifera					p1
Hymenophyllum triangulare					m1
Haplopteris guineensis					p1
Bulbophyllum cochleatum					r1
Rutidea fuscescens					r1
Commelina sp. II					p1
Asplenium rukararense					r1
Cissus cf. oliveri					p1
Bulbophyllum cf. kivuense					r1
Secamone cf. racemosa					r1
Psychotria sp. III					p2
Hymenophyllum floribundum					p1

Further species in the samples: 3_{NU}: Polypodiales sp. III r1; 79_{NGk}: Cucurbitaceae sp. III r1; Gen. indet. spec. indet. LXXXI r1; Gen. indet. spec. indet. LXXXIII r1; Apocynaceae sp. VIII p1; Bryopsida sp. III a1

3.2.15 *Magnistipula butayei-Macaranga kilimandscharica-Carapa grandiflora* Community

Fuzzy k-means cluster number: M15
UPGMA, local cut information level: 70 % (to plot 3_{NU})
Plots: 20_{NG}

Locations: Nyungwe, Gisovu

M15	3_{NU}	11_{NU}	20_{NG}	42_{NK}
3_{NU}	0	0.72	0.65	0.76
11_{NU}		0	0.6	0.6
20_{NG}			0	0.41
42_{NK}				0

Table 3.30: Bray-Curtis dissimilarities between the samples discussed.

M15	3_{NU}	11_{NU}	20_{NG}	42_{NK}
3_{NU}	0	0.72	0.65	0.76
11_{NU}		0	0.6	0.59
20_{NG}			0	0.41
42_{NK}				0

Table 3.31: Geographic distances between the samples discused in km.

With a dissimilarity of 65%, plot 20_{NG} is the second most similar to plot 3_{NU}. This result is also reflected within the UPGMA derived dendrogram, where plot 3_{NU} is the first joint of plot 20_{NG}. The branching occurs at the 70% information level. At first glance, both plots might be subsumed under a *Carapa-Macaranga* community. Here, the presence of *Magnistipula butayei*, as a dominant species in the canopy of plot 20_{NG}, would be ignored. Again, undersampling poses a hindrance to a sound classification. With a dissimilarity of only 41%, plot 20_{NG} is more similar to plot 42_{NK}. Despite the higher resemblance, it is still not advisable to group the two sampling sites. Plot 42_{NK} near Kitabi is firmly embedded into another cluster (see 3.2.16). Inserting sample 20_{NG} would introduce a higher degree of arbitrariness, and the same is almost valid for plot 11_{NU} with which the dissimilarity amounts to 60%. When examining species composition, the differences that arise do not allow for a reasonable joint classification with any of the sites showing at least some similarity. In terms of the consecutive memberships computed by FCM-NC, plot 20_{NG} is positioned right between cluster M28 and M35 and also shows some similarities to cluster M20. A closer look at the respective species composition, i.e., overlaps and the Bray-Curtis values, does not resolve the situation. Thus, remaining in indecision, the site should remain as a cluster of its own. The site is situated at the medium level of the montane rain forest and faces SW. With a drillable soil depth of 0.55 m in the clay soil, a measurement of the temperature is rendered infeasible. The pH value is measured at 3.09. The site holds three tree layers the tallest of which reaches 28 m. Shrub cover is about 20%, and the herbal layer covers about 10% of the ground. When it comes to vegetation composition and subsequent classification, none of the communities described so far make for a convincing assignment. A few similarities to Fischer's (1996) *Albizia gummifera-Carapa grandiflora-Parinari excelsa* forests can be found, but an allocation to this unit would be more of a sophisticated guess. For *Magnistipula butayei*, no information could be retrieved as to the constituent character of the species for a vegetation unit. As a working title, *Magnistipula butayei-Macaranga kilimandscharica-Carapa grandiflora* community has to fill the gap for the time being.

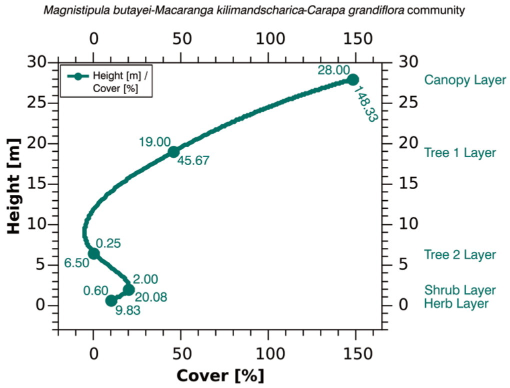

Figure 3.23: Cover-Height relation of the community recovered in Gisovu; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Table 3.32: *Magnistipula butayei-Macaranga kilimandscharica-Carapa grandiflora* community

Sample Site / Species	3_{NU}	11_{NU}	20_{NG}	42_{NK}
Exposition	E	NE	SW	NNW
Inclination [°]	0	9	n/a	21.5
Position / Relief	KS	HO	HM	MH
Precipitation / a [mm]	1881	1881	1581	1631
Elevation a.s.l. [m]	2501	2498	2216	2302
$T\ S_{60}$ [°C]	14.00	13.00	n/a	16.00
pH	2.71	2.76	3.09	2.59
Soil texture	Ut	Ts	Ts	Sl
t Height [m]	15.5	22	28	25.5
t1 Height [m]	8	14	19	16
t2 Height [m]	n/a	8	6.5	4
t3 Height [m]	n/a	n/a	n/a	n/a
Shrub Height [m]	3.5	2	2	n
Herb Height [m]	0.6	0.6	0.6	0.9
Moss Height [m]	n/a	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	1	0	1	1
Vegetation Cover [Londo]	10	10	10	10
t Cover [%]	84.17	95.42	148.33	128.75
t1 Cover [%]	26.67	20.33	45.67	45.83
t2 Cover [%]	0	0.67	0.25	4.50
t3 Cover [%]	0	0	0	0
Shrub Cover [%]	28.33	13.42	20.08	0
Herb Cover [%]	46.75	43.67	9.83	97.50
Moss Cover [%]	n/a	n/a	n/a	n/a
Juvenil Cover [Londo]	4	2	0.7	a1
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	n/a
Macaranga kilimandscharica	1.2	9	6	7
Carapa grandiflora	5-	1.2	5-	2
Chassalia subochreata	2	0.7	p2	p1
Syzygium parvifolium	2	0.7		2
Asplenium sandersonii	p1	p2	p1	
Asplenium sp. II	p1	r1	m1	
Rytigynia kigeziensis	p1	p1		
Psychotria mahonii	0.7	p2		
Astropanax goetzenii	2	r1		
Embelia libeniana	r1	p4		
Mikania cordata	p1		r1	
Oxyanthus troupinii	r1		r1	
Mikaniopsis sp.		0.7	p2	
Sericostachys scandens		r1	p1	
Mimulopsis excellens			m1	10
Magnistipula butayei			8	7
Asplenium sp. IV		p1		p1
Mikaniopsis tedliei	1.2			
Sericanthe leonardii	r1			
Asplenium erectum	p1			
Asplenium tenuicaudatum	r1			
Asplenium bugoiense	r1			
Vittaria reekmansii	p1			
Balthasaria schliebenii	r1			
Myrsine melanophloeos	r1			
Asplenium friesiorum	p2			

Table 3.32: *Magnistipula butayei-Macaranga kilimandscharica-Carapa grandiflora* community (continued)

Sample Site / Species	3_{NU}	11_{NU}	20_{NG}	42_{NK}
Myrsine cf. melanophloeos	r1			
Cyperus subgen. Mariscus	r1			
Asplenium cf. gemmiferum	r1			
Blotiella stipitata	p1			
Asplenium sp.	p1			
Isachne mauritiana	p1			
cf. Asplenium sp. XXVII	r1			
Impatiens purpureo-violacea		1.2		
Impatiens gesneroidea		p2		
Begonia meyeri-johannis		p1		
Pavetta rwandensis		p1		
Clutia abyssinica		r1		
Stephania abyssinica		r1		
Mimulopsis solmsii		r1		
Pavetta bagshawei		p1		
Impatiens cf. warburgiana		r1		
Crassocephalum rubens		r1		
Cyperus sp.		p1		
Mikaniopsis sp. I		r1		
Asplenium dregeanum		p1		
Dryopteris sp. II		r1		
Blotiella cf. bouxiniana		r1		
Alchornea hirtella			1.2	
Parinari excellsa			0.7	
Coleus melleri			0.7	
Phyllanthus nummularifolius			p1	
Isoglossa vulcanicola			p1	
Strombosia scheffleri			r1	
Sanicula elata			r1	
Lasianthus kilimandscharicus			r1	
Symphonia globulifera			p1	
Dracaena laxissima			p1	
Impatiens purpureo-violacea s. l.			p1	
Pteris cf. catoptera			p1	
Rubus sp. VIII			r1	
Athyrium sp.			p2	

Further species in the samples: **11_{NU}**: Polypodiales sp. X r1; Polypodiales sp. III r1; **42_{NK}**: Gen. indet. spec. indet. LVIII r1; Gen. indet. spec. indet. XCIX r1; Gen. indet. spec. indet. LIX r1

3.2.16 *Macaranga-Chassalia subochreata-Mimulopsis excellens* Community

Fuzzy k-means cluster number: M20
UPGMA, local cut information level: 94 %
Plots: 38_{NGa}, 39_{NGa}, 40_{NGa}, 42_{NK}, 45_{NK}

Locations: Nyungwe Gahurizo, Kitabi

M20	38_{NGa}	39_{NGa}	40_{NGa}	42_{NK}	45_{NK}
38_{NGa}	0	0.24	0.39	0.32	0.11
39_{NGa}		0	0.52	0.47	0.22
40_{NGa}			0	0.47	0.42
42_{NK}				0	0.34
45_{NK}					0

Table 3.33: Bray-Curtis dissimilarities between the samples discussed.

M20	38_{NGa}	39_{NGa}	40_{NGa}	42_{NK}	45_{NK}
38_{NGa}	0	0.11	0.04	11.64	11.74
39_{NGa}		0	0.08	11.68	11.79
40_{NGa}			0	11.62	11.73
42_{NK}				0	0.11
45_{NK}					0

Table 3.34: Geographic distances between the samples discused in km.

All the sites are situated at the medium level of the montane rain forest and face NNW in most cases. The drillable soil depth is in the midrange of the survey at hand and does not fall below 0.92 m. The measured mean annual temperature varies between 15 and 16°C. The pH value of the sandy to silty soils varies between 3.13 and 2.59. Three of the sites hold three tree layers and the remaining sites only two. The canopy height can get as low as 25 m and does not exceed 28 m. The shrub layer is not well developed in most cases, while the herb layer reaches more than 90% in most of the plots.

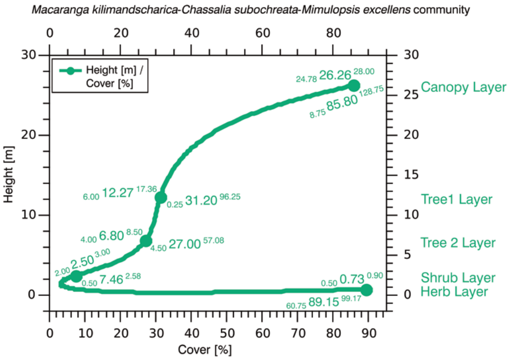

Figure 3.24: Cover-Height relation of the community recovered at the eastern site of Nyungwe Forest; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

The plots around Gahurizo and Kitabi at the eastern border of Nyungwe Forest are mainly connected by *Macaranga kilimandscharica*, which is dominant in the canopy. *Chassalia subochreata* occurs in the shrub layer in only low abundances. *Psychotria mahonii* is present in three of the five sites, as is *Allophylus chaunostachys*. The same is valid for *Ilex mitis*. A yet unidentified *Asplenium sp. IV* occurs in all five plots. The inventory of the herb layer is shaped by *Mimulopsis excellens*, which occurs with an abundance of up to a 100% in most of the plots. FISCHER (1996) described similar forests in the Kahuzi-Biega National Park as *Macaranga kilimandscharica* secondary forests. However, the *Macarango-Psychotrietum mahonii* described by HABIYAREMYE (1997) is not applicable per se. Some of the species HABIYAREMYE (ibid.) deemed characteristic were not found. *Peddiea rapaneoides* is completely missing, and the same is true for *Rutidea fuscescens*. The *Embelia sp.* found could not be identified at the species level, and thus, the presence of *E. schimperi* could not be ascertained. *Asplenium friesiorum* could only be identified with some uncertainty. Nevertheless, the author would assign the community at hand to the class *Musango-Terminalietea* LEBRUN & GILBERT 1954, order *Polyscietalia fulvae* LEBRUN & GILBERT 1954 and the alliance *Polyscion fulvae* LEBRUN & GILBERT 1954. A *Macaranga-Chassalia subochreata-Mimulopsis excellens* community should be an adequate denomination here. Cutting the UPGMA tree locally at the 94% information level, results in the same grouping as the one derived from FCM-NC.

Table 3.35: *Macaranga-Chassalia subochreata-Mimulopsis excellens* community

Sample Site / Species	^{38}NGa	^{39}NGa	^{40}NGa	^{42}NK	^{45}NK
Exposition	NNW	NE	ESE	NNW	NNW
Inclination [°]	10	17	11	21.5	31.5
Position / Relief	KH	KH	KH	MH	HU
Precipitation / a [mm]	1629	1629	1629	1631	1631
Elevation a.s.l. [m]	2429	2419	2428	2302	2254
T S_{60} [°C]	n/a	n/a	n/a	16.00	15.10
pH	2.89	2.94	2.77	2.59	3.13
Soil texture	Us	Sl	Sl	Sl	Us
t Height [m]	25.5	24.78	28	25.5	27.55
t1 Height [m]	16	6	17.36	16	6
t2 Height [m]	8	n/a	8.5	4	n/a
t3 Height [m]	n/a	n/a	n/a	n/a	n/a
Shrub Height [m]	2.5	2.5	2.5	n/a	3
Herb Height [m]	0.8	0.85	0.5	0.9	0.6
Moss Height [m]	n/a	n/a	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1	1	1
Vegetation Cover [Londo]	10	10	10	10	10
t Cover [%]	8.75	100.67	93.33	128.75	97.50
t1 Cover [%]	96.25	7.92	0.25	45.83	5.75
t2 Cover [%]	19.42	0	57.08	4.50	0
t3 Cover [%]	0	0	0	0	0
Shrub Cover [%]	2.58	24.5	<1	<1	2.25
Herb Cover [%]	99.17	60.75	97.50	97.50	90.83
Moss Cover [%]	n/a	n/a	n/a	n/a	n/a
Juvenil Cover [Londo]	a1	a4	p2	a1	a1
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	n/a	n/a
Macaranga kilimandscharica	10	10	4	7	10
Mimulopsis excellens	10	6	10	10	9
Asplenium sp. IV	r1	a1	p1	p1	r1
Chassalia subochreata	p1	p2		p1	r1
Psychotria mahonii		p1	r1		r1
Allophylus chaunostachys	p1	r1	p1		
Ilex mitis	0.7	p2	r4		
Carapa grandiflora	p1			2	
Syzygium parvifolium	r2			2	
Asplenium sandersonii	r1	r1			
Impatiens purpureo-violacea	p2	p1			
Sericostachys scandens	p1	a4			
Asplenium cf. friesiorum	p1		r1		
Galiniera saxifraga		0.7	1.2		
Olinia rochetiana		r1	9		
Blotiella glabra	p1				r1
Asplenium sp. VI	r1				r1
Cyperus sp. III		p1			p1
Urera hypselodendron	r1				
Gynura scandens	r1				
Asplenium friesiorum	p1				
Tridactyle sp.	r1				
Asplenium cf. reekmansii	r1				
Asplenium sp. II	r1				
Mimulopsis solmsii		p2			
Xymalos monospora		2			

Table 3.35: *Macaranga-Chassalia subochreata-Mimulopsis excellens* community (continued)

Sample Site / Species	38_{NGa}	39_{NGa}	40_{NGa}	42_{NK}	45_{NK}
Begonia meyeri-johannis		a4			
Monanthotaxis orophila		p1			
Dracaena afromontana		r1			
cf. Mimulopsis solmsii		r1			
Asplenium cf. erectum		r1			
Rutidea orientalis		p2			
Ochna afzelii		r1			
Asplenium sp. XXIV		p1			
Asplenium aff. elliottii		p1			
Astropanax goetzenii			p1		
Keetia gueinzii			p1		
Salacia sp. I			p1		
Marsdenia angolensis			p1		
Magnistipula butayei				7	
Parinari excellsa					r1
Symphonia globulifera					r1
Pilea rivularis					p1
Impatiens gesneroidea					p1
Clutia abyssinica					r2
Dryopteris sp. IX					p1
Crassocephalum sp.					r1
Embelia sp.					r1
Rytigynia sp. V					p1
Erythrococca cf. atrovirens					p1

Further species in the samples: **38_{NGa}**: Gen. indet. spec. indet. LVIII p1; Rubiaceae sp. VI 0,7; Gen. indet. spec. indet. XCIII p1; **39_{NGa}**: Gen. indet. spec. indet. LVIII p1; Gen. indet. spec. indet. XCVI p1; Acanthaceae sp. I p1; Gen. indet. spec. indet. XCV p1; Gen. indet. spec. indet. XCIV r1; **40_{NGa}**: Gen. indet. spec. indet. XCVIII r1; cf. Rubiaceae sp. r1; **42_{NK}**: Gen. indet. spec. indet. LVIII r1; Gen. indet. spec. indet. XCIX r1; Gen. indet. spec. indet. LIX r1; **45_{NK}**: Gen. indet. spec. indet. CVII r1; Apocynaceae sp. p4

3.2.17 *Triumfetta cordifolia-Brillantaisia owariensis* Community

Fuzzy k-means cluster number: M16
UPGMA, local cut information level: 0 %
Plots: 10_{NU} Locations: Nyungwe, Uwinka

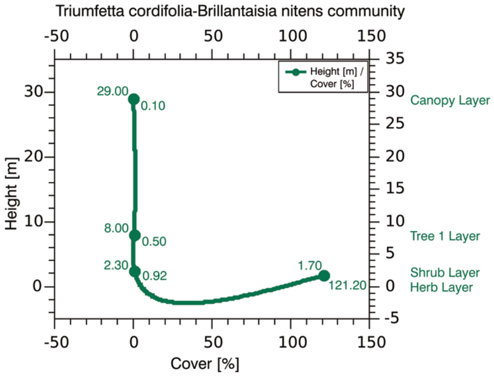

Figure 3.25: Cover-Height relation of the community recovered close to Uwinka; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

As one of the few canopy-free, i.e., completely open plots, it is no wonder that plot 10_{NU} is ostracised into a cluster of its own. Not even the more open plots like 14_{NG}, 44_{NK}, 38_{NGa}, 46_{NK} and 15_{NG} show a sign of similarity. The most similar plots 14_{NG} with 99% and 86_{Gw} with 96% dissimilarity respectively, are likewise not to be integrated. Moreover, sample site 10_{NU} seems to have been subjected to a landslide. Thus, the vegetation represents an early stage of succession and, as such, may exhibit a mixture of species representing any stage from pioneers to relic species of the vegetation cover prior to the disturbance event. Since the author wishes not to disfigure the rules of syntaxonomy, incorporation into the established system will not be undertaken. A proposed working title would be *Triumfetta cordifolia-Brillantaisia owariensis* community. The community could then be subsumed under a higher syntaxonomic unit comprised of communities in natural clearings.

Other than that, the site is part of the mid-level montane rain forest. It faces west and exhibits a loamy soil with a low silt percentage. The drillable soil depth exceeds 1.75 m. Soil temperature at 0.60 m depth is 13.50 °C while the pH is 3.71. Canopy cover occurs only as a fringe phenomenon and a potential second tree layer is only present in the form of a single, partially overgrown specimen of *Cassipourea ruwensorensis*.

Table 3.36: *Triumfetta cordifolia-Brillantaisia owariensis* community

Sample Site / Species	10_{NU}
Exposition	S
Inclination [°]	25
Position / Relief	HM
Precipitation / a [mm]	1881
Elevation a.s.l. [m]	2474
T S_{60} [°C]	13.50
pH	3.71
Soil texture	Lu
t Height [m]	29
t1 Height [m]	8
t2 Height [m]	n/a
t3 Height [m]	n/a
Shrub Height [m]	2.3
Herb Height [m]	1.7
Moss Height [m]	n/a
Juvenil Height [m]	n/a
Epiphyts [m/6m]	1
Vegetation Cover [Londo]	10
t Cover [%]	<1
t1 Cover [%]	<1
t2 Cover [%]	0
t3 Cover [%]	0
Shrub Cover [%]	0.92
Herb Cover [%]	121.20
Moss Cover [%]	n/a
Juvenil Cover [Londo]	n/a
Juvenil Shrub Cover [Londo]	n/a
Triumfetta cordifolia	3
Brillantaisia owariensis	2
Rubus apetalus	2
Impatiens sp.	2
Mikania sp.	2
Coleus maculosus subsp. edulis	1.2
Urera hypselodendron	p4
Cassipourea ruwensorensis	r1
Pteridium aquilinum	p1
Momordica foetida	p1
Sericostachys scandens	p2
Baccharioides kirungae	p1
Bersama abyssinica	r1
Neoboutonia macrocalyx	r1
Isodon ramosissimus	r1
Crassocephalum montuosum	r1
Sonchus cf. bipontini	r1
Rubus rigidus	r1
Microlepia speluncae	p2
Christella sp.	p2
Clematis cf. simensis	p1

3.2.18 *Polyscias-Carapa grandiflora-Neoboutonia* Secondary Community

Fuzzy k-means cluster number: M18
UPGMA, local cut information level:
Plots: 21_{NG}

Locations: Nyungwe, Gisovu

M18	^{3}NU	^{21}NG	^{33}NGa	^{43}NK	^{44}NK	^{51}NGs	^{68}NBw	^{75}NM
^{3}NU	0	0.75	0.88	0.90	0.92	0.68	0.95	0.91
^{21}NG		0	0.91	0.73	0.97	0.77	0.72	0.97
^{33}NGa			0	0.45	0.5	0.98	0.94	0.53
^{43}NK				0	0.55	0.98	0.74	0.61
^{44}NK					0	0.99	0.94	0.51
^{51}NGs						0	0.99	1
^{68}NBw							0	0.94
^{75}NM								0

Table 3.37: Bray-Curtis dissimilarities between the samples discussed.

M18	^{3}NU	^{21}NG	^{33}NGa	^{43}NK	^{44}NK	^{51}NGs	^{68}NBw	^{75}NM
^{3}NU	0	25.94	30.23	23.60	25.23	13.53	13.06	23.55
^{21}NG		0	41.92	29.82	30.57	37.06	36.52	11.82
^{33}NGa			0	12.31	12.04	39.75	21.92	31.01
^{43}NK				0	1.64	35.85	21.05	18.71
^{44}NK					0	37.48	22.54	19.23
^{51}NGs						0	18.15	36.77
^{68}NBw							0	30.47
^{75}NM								0

Table 3.38: Geographic distances between the samples discused in km.

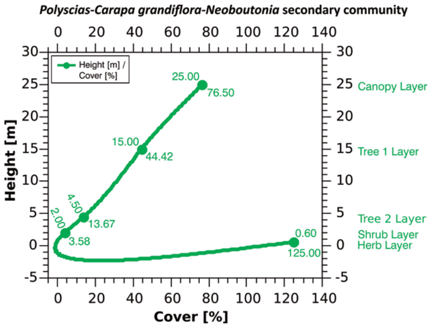

Figure 3.26: Cover-Height relation of the community recovered close to Gisovu; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

When it comes to plot 21_{NG}, the clustering methods used offer different results as to the grouping of the sample site. Fuzzy c-means puts the site into a cluster of its own, while the secondary membership lies within the noise cluster. Only jointed at the 48% information level, UPGMA places the site closest to plot 51_{NGs} and, in turn, also to plot 3_{NU}, with respective dissimilarities of about 77% and 75%. Plot 43_{NK} seems to be the most similar to plot 21_{NG}; both belong, without a doubt, to the order Polyscietalia fulvae maybe even the alliance Polyscion fulvae. The differing shares of *C. grandiflora*, *M. kilimandscharica* and *P. fulva* would not pose as a hinderance to subsume both plots under the same vegetation unit. Since plot 43_{NK} is firmly incorporated into cluster M28 and the dissimilarities to the other sites border on 100%, a combination of the sites at this point seems rather volatile. The same is valid for plot 68_{NBw} but to a lesser extent. For now, a *Polyscias-Carapa grandiflora-Neoboutonia* secondary community should be set up as a placeholder.

The site which faces SE is positioned at the transition from the lower to the mid-level of the montane forest. The relatively shallow soil has a pH of 3.22. Since the depth of the sandy soil was not sufficient, the temperature could not be determined. The 25 m high canopy covers two more tree layers, a sparse shrub and a not very well-developed herb layer.

Table 3.39: *Polyscias-Carapa grandiflora-Neoboutonia* secondary community

Sample Site / Species	51$_{NGs}$	3$_{NU}$	21$_{NG}$	43$_{NK}$	68$_{NBw}$
Exposition	NNW	O	SO	NW	SW
Inclination [°]	43	0	7	26	51
Position / Relief	HM	KS	TS	OH	HM
Precipitation / a [mm]	2211	1881	1581	1647	1836
Elevation a.s.l. [m]	1684	2501	2228	2316	1811
T S_{60} [°C]	n/a	14.00	n/a	14.90	17.00
pH	3.99	2.71	3.22	3.07	3.38
Soil texture	Ts	Ut	Sl	Sl	Sl
t Height [m]	24.29	15.5	25	24.3	12.5
t1 Height [m]	11.5	8	15	15.2	9
t2 Height [m]	8.5	n/a	4.5	n/a	4
t3 Height [m]	3	n/a	n/a	n/a	n/a
Shrub Height [m]	2.3	3.5	2	3.1	2.5
Herb Height [m]	1	0.6	0.6	1	0.9
Moss Height [m]	0.06	n/a	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1	1	1
Vegetation Cover [Londo]	10	10	10	10	10
t Cover [%]	82.55	84.17	76.50	64.00	48.58
t1 Cover [%]	42.00	26.67	44.42	13.49	38.25
t2 Cover [%]	59.83	0	13.67	0	3.17
t3 Cover [%]	0.5	0	0	0	0
Shrub Cover [%]	7.00	28.33	3.58	18.17	21.17
Herb Cover [%]	9.83	46.75	12.50	23.58	37.17
Moss Cover [%]	n/a	n/a	n/a	n/a	n/a
Juvenil Cover [Londo]	p1	4	p4	a1	a1
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	n/a	n/a
Carapa grandiflora	8	5-	3	p1	
Macaranga kilimandscharica		1.2	p4	5-	0.7
Polyscias fulva			7	3	4
Allophylus chaunostachys	r1		r1	r1	
Chassalia subochreata		2	p1		
Psychotria mahonii		0.7	p1		
Rytigynia kigeziensis		p1	p1		
Asplenium sandersonii		p1	p1		
Mikania cordata		p1	r1		
Asplenium sp. II		p1	r1		
Galiniera saxifraga			p2	p1	
Neoboutonia macrocalyx			2	r1	
Pilea rivularis			p1	p1	
Clerodendrum johnstonii			p1	p1	
Cyperus sp. III				r1	p1
Alangium chinense	4		r1		
Myrianthus holstii	r1		p1		
Piper capense	a1		p1		
Symphonia globulifera	r1		p2		
Dracaena laxissima	r1		p4		
Syzygium parvifolium		2		p1	
Isachne mauritiana		p1			2
Mimulopsis arborescens	p1			p1	
Shirakiopsis elliptica	r1				p1
Musanga leo-errerae	4				
Maesopsis eminii	3				

Table 3.39: *Polyscias-Carapa grandiflora-Neoboutonia* secondary community (continued)

Sample Site / Species	^{51}NGs	^{3}NU	^{21}NG	^{43}NK	^{68}NBw
Impatiens cf. erecticornis	a2				
Asplenium dregeanum	m1				
Dryopteris sp. IX	r1				
Pteris cf. preussii	p1				
Tiliacora funifera	r1				
Entandrophragma excelsum	p1				
Microcos mildbraedii	r1				
Culcasia falcifolia	p1				
Porotrichum variifolioides	r1				
Tectaria cf. coadunata	p1				
Elatostema sp.	p1				
Dryopteris sp. VI	p1				
cf. Dryopteris sp. XIV	p1				
Allophylus abyssinicus	p1				
Illigera pentaphylla	r1				
Tectaria sp. IV	p1				
Boehmeria cf. virgata subsp. macrophylla	r1				
Dryopteris sp. XVII	p1				
cf. Begonia sp.	p1				
Pteris cf. auquieri	p1				
Tectaria gemmifera	p2				
Antrophyum mannianum	p1				
Pteris sp.	r1				
Palisota mannii	p1				
Didymochlaena truncalata	p4				
Celosia sp.	p1				
Ampelopteris sp.	p1				
Sericostachys sp. II	p1				
Pseudospondias microcarpa	r1				
Acanthus ueleensis	r1				
Kigelia africana subsp. africana	p1				
cf. Cola pierlotii	r1				
Psychotria aff. peduncularis	r1				
Ficus asperifolia	r1				
Clausena anisata	p1				
Psychotria sp. II	r1				
cf. Tabernaemontana sp.	r1				
Asplenium africanum	p1				
Ficus sur	r1				
Tabernaemontana stapfiana	r1				
Marattia sp.	r1				
Astropanax goetzenii		2			
Mikaniopsis tedliei		1.2			
Sericanthe leonardii		r1			
Asplenium erectum		p1			
Embelia libeniana		r1			
Oxyanthus troupinii		r1			
Asplenium tenuicaudatum		r1			
Asplenium bugoiense		r1			
Vittaria reekmansii		p1			
Balthasaria schliebenii		r1			
Myrsine melanophloeos		r1			
Asplenium friesiorum		p2			

Table 3.39: *Polyscias-Carapa grandiflora-Neoboutonia* secondary community (continued)

Sample Site / Species	^{51}NGs	^{3}NU	^{21}NG	^{43}NK	^{68}NBw
Myrsine cf. melanophloeos		r1			
Cyperus subgen. Mariscus		r1			
Asplenium cf. gemmiferum		r1			
Blotiella stipitata		p1			
Asplenium sp.		p1			
cf. Asplenium sp. XXVII		r1			
Casearia runssorica			p1		
Salacia erecta			r1		
Embelia schimperi			p1		
Phyllanthus nummularifolius			p1		
Xymalos monospora			p2		
Strombosia scheffleri			r1		
Laportea alatipes			p1		
Olea capensis ssp. hochstetteri			r1		
Elatostema monticola			p1		
Peperomia sp.			p1		
Rourea thomsonii			r1		
cf. Pilea bambuseti			p1		
Prunus africana			p1		
Sanicula elata			p2		
Bothriocline ruwenzoriensis			p1		
Keetia sp. I			r1		
Athyrium newtonii			p1		
Pteris sp. II			p2		
Pteris cf. dentata			p1		
Cyphostemma sp. I			r1		
Mikaniopsis sp.			p1		
Rinorea angustifolia ssp. engleriana			p1		
Hypolepis sparsisora				1.2	
Mikania chenopodiifolia				1.2	
Begonia meyeri-johannis				0.7	
Pilea bambuseti				p1	
Blotiella glabra				p1	
Ipomoea involucrata				p1	
Sericostachys scandens				p1	
Coccinia mildbraedii				p1	
Triumfetta cordifolia				p1	
Clutia abyssinica				p1	
Impatiens gesneroidea				a1	
Urera hypselodendron				p1	
Coleus sylvestris				p1	
Rubus cf. pinnatus				p1	
Coccinia sp.				p2	
Diplazium sp. VI				p1	
Dichanthelium hillebrandianum				a1	
Maesa lanceolata					4
Arthropteris cf. monocarpa					2
Leptactina platyphylla					1.2
Urera trinervis					0.7
Drymaria cordata					p1
Asplenium cf. friesiorum					r1
Rubus cf. apetalus					p1
Gouania longispicata					p1

Table 3.39: *Polyscias-Carapa grandiflora-Neoboutonia* secondary community (continued)

Sample Site / Species	51NGs	3NU	21NG	43NK	68NBw
Ritchiea albersii					r1
Zanthoxylum gilletii					r1
Canarina eminii					p1
Isoglossa sp.					r1
Pteris sp. VI					p1
Croton macrostachyus					p4
Grona cf. ramosissima					p1
Rubus cf. pinnatus					r1
cf. Lobelia giberroa					p1
Tristemma sp.					r1
Ficus sp. VII					r1
Anthocleista grandiflora					r1
Ficus natalensis					r1

Further species in the samples: **3NU**: Apocynaceae sp. I: p1; Rubiaceae sp. II: r1; Polypodiales sp. III: r1; **21NG**: Apocynaceae sp. I: p1; **43NK**: Rubiaceae sp. VI: p1; Gen. indet. spec. indet. CI: p1; **51NGs**: Poaceae sp. VI: p1; Gen. indet. spec. indet. CXXXVI: r1; Acanthaceae sp. III: p1; Gen. indet. spec. indet. CXXIX: r1; Polypodiales sp. XI: p1; Lilianae sp.: r1; Gen. indet. spec. indet. CXXX: p1; Polypodiales sp. XIV: r1; Polypodiales sp. XVII: p2; Woodsiaceae sp. VII: p1; Cucurbitaceae sp. VI: r1; Gen. indet. spec. indet. CXXXII: p1; Cucurbitaceae sp. I: r1; Gen. indet. spec. indet. CXXXVII: r1; Gen. indet. spec. indet. CXXXIV: r1; Gen. indet. spec. indet. CXXXIII: r1; **68NBw**: Gen. indet. spec. indet. XXIV: r1; Bonny repens: r1; Gen. indet. spec. indet. XXV: p4; Gen. indet. spec. indet. XXXI: r1; Gen. indet. spec. indet. XXX: r1; **21NG:** Rubiaceae sp. II r1

3.2.19 *Maesa lanceolata-Macaranga kilimandscharica-Arthropteris monocarpa* Community

Fuzzy k-means cluster number: M14
UPGMA, local cut information level: 68 %
Plots: 66_{NBw}, 67_{NBw}, 68_{NBw}

Locations: Nyungwe, Bweyeye

M14	66NBw	67NBw	68NBw
66NBw	0	0.59	0.72
67NBw		0	0.53
68NBw			0

Table 3.40: Bray-Curtis dissimilarities between the samples discussed.

M14	66NBw	67NBw	68NBw
66NBw	0	1.83	1.88
67NBw		0	0.22
68NBw			0

Table 3.41: Geographic distances between the samples discused in km.

Situated close to Bweyeye, these sites face SW and NNW at an altitude between 1850 to about 2000 m a.s.l. The annual mean temperature varies between 16.30 and 17.70°C. The pH measured in the loamy sands and sandy clays is between 3.38 and 4.02. The highest of the three tree layers reaches a maximum of 19 m and also covers a shrub and herb layer.

The three plots show *Maesa lanceolata* at an intermediate to high abundance distributed over the tallest and second tallest tree layer. In plot 67_{NBw}, *Shirakiopsis elliptica* and *Harungana montana* occur in minor abundances. In plot 68_{NBw}, *Polyscias fulva* dominates the crown stratum accompanied by *Macaranga kilimandscharica* and, as already mentioned, *M. lanceolata*. *Polyscias* is also occurring in the third tree layer but only to a minute extent. *Croton macrostachyus* has a moderate share in the crown layer of plot 66_{NBw}, which is otherwise dominated by *Maesa lanceolata*. In this plot, *M. lanceolata* also dominates the third tree layer with almost 100% coverage. *Sericostachys scandens* can be found in plot 66_{NBw} from the herb up into the second tree layer, covering a total of 60% of the site. All plots share an occurrence of *M. kilimandscharica* in the second tree layer. In plot 68_{NBw} regrowth can be found in the shrub layer. *Urera trinervis* is twining from the herb via the shrub into the third tree layer and the second tree layer within two of the plots, respectively. Further commonalities are modest, and *Rubus cf. apetalus*, *Gouania longispicata*, *Shirakiopsis elliptica*, *Pteris sp. VI*, *Croton macrostachyus* are the shared species. *Arthropteris cf. monocarpa* is the only species shared by two plots which occurs with moderate ground cover.

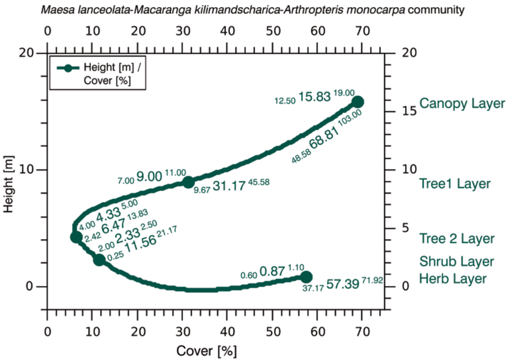

Figure 3.27: Cover-Height relation of the community recovered near Bweyeye; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

With a local cut at the 68% information level, UPGMA gives the same result as FCM-NC. Vegetation composition allows for an unequivocal classification into secondary forests. Further assignments, according to existing classifications, are rather cumbersome. The class Musango-Terminalietea LEBRUN & GILBERT 1954 comprises the order Polyscietalia fulvae within which the community might be set as *Maesa lanceolata-Macaranga kilimandscharica-Arthropteris monocarpa*.

Table 3.42: *Maesa lanceolata-Macaranga kilimandscharica-Arthropteris monocarpa* community

Sample Site / Species	66_{NBw}	67_{NBw}	68_{NBw}
Exposition	SW	NNW	SW
Inclination [°]	20	22	51
Position / Relief	HM	HO	HM
Precipitation / a [mm]	1865	1836	1836
Elevation a.s.l. [m]	2012	1893	1811
T S_{60} [°C]	16.30	17.70	17.00
pH	4.02	3.39	3.38
Soil texture	Ts	Sl	Sl
t Height [m]	16	19	12.5
t1 Height [m]	11	7	9
t2 Height [m]	5	4	4
t3 Height [m]	n/a	n/a	n/a
Shrub Height [m]	2.5	2	2.5
Herb Height [m]	1.1	0.6	0.9
Moss Height [m]	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1
Vegetation Cover [Londo]	10	10	10
t Cover [%]	103	54.83	48.58
t1 Cover [%]	9.67	45.58	38.25
t2 Cover [%]	13.83	2.42	3.17
t3 Cover [%]	0	0	0
Shrub Cover [%]	13.25	0.25	21.17
Herb Cover [%]	63.08	71.92	37.17
Moss Cover [%]	n/a	n/a	n/a
Juvenil Cover [Londo]	n/a	p1	a1
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a
Maesa lanceolata	8	7	4
Macaranga kilimandscharica	p1	0.7	0.7
Croton macrostachyus	3	r1	p4
Rubus cf. apetalus	r1	p1	p1
Gouania longispicata	p4	p1	p1
Shirakiopsis elliptica	r1	p1	p1
Pteris sp. VI	p1	p1	p1
Arthropteris cf. monocarpa		4	2
Urera trinervis		p4	0.7
Polyscias fulva		r1	4
Drymaria cordata		p1	p1
Asplenium cf. friesiorum		a1	r1
Grona cf. ramosissima		p4	p1
Alchornea hirtella	r1	p1	
Asplenium sandersonii	p1	r1	
Mimulopsis arborescens	p1	a1	
Psychotria peduncularis	p1	r1	
Bridelia brideliifolia	r1	r1	
Isoglossa sp.	p1		r1
Sericostachys scandens	6		
Begonia meyeri-johannis	p4		
Urera hypselodendron	p1		
Triumfetta cordifolia	p1		
Neoboutonia macrocalyx	p1		

Table 3.42: *Maesa lanceolata-Macaranga kilimandscharica-Arthropteris monocarpa* community (continued)

Sample Site / Species	66_{NBw}	67_{NBw}	68_{NBw}
Mimulopsis excellens	p1		
Laportea alatipes	p1		
Alangium chinense	p1		
Pleopeltis macrocarpa	r1		
Asplenium aff. elliottii	p1		
Clerodendrum buchananii	p2		
Pteris cf. pteridioides	r1		
Pteris sp. V	p1		
cf. Cucumis sp. I	p1		
Asplenium cf. tenuicaudatum	p1		
Piper cf. capense	p1		
Cucumis sp. I	r1		
Bersama abyssinica var. engleriana	p1		
Poecilostachys oplismenoides		3	
Hymenodictyon floribundum		1.2	
Harungana montana		0.7	
Allophylus chaunostachys		r1	
Apodytes dimidiata		r1	
Landolphia buchananii		p1	
Asplenium sp. IV		p1	
Asplenium cf. mildbraedii		r1	
Monosis conferta		p4	
cf. Microlepia speluncae		r1	
cf. Stellaria sp.		p1	
Mikania sp. IV		p1	
Zehneria sp. II		r1	
Orbivestus karanguensis		r1	
Peponium vogelii		r1	
Solanum chrysotrichum		p1	
Isachne mauritiana			2
Leptactina platyphylla			1.2
Cyperus sp. III			p1
Ritchiea albersii			r1
Zanthoxylum gilletii			r1
Canarina eminii			p1
Rubus cf. pinnatus			r1
Bonny repens			r1
cf. Lobelia giberroa			p1
Tristemma sp.			r1
Ficus sp. VII			r1
Anthocleista grandiflora			r1
Ficus natalensis			r1

Further species in the samples: **66_{NBw}**: Amaranthaceae sp. 2; Gen. indet. spec. indet. XVIII p1; Gen. indet. spec. indet. XIX r1; Vernonieae sp. p1; **67_{NBw}**: Gen. indet. spec. indet. XXIV r1; Apocynaceae sp. II p1; Gen. indet. spec. indet. XXII p1; Gen. indet. spec. indet. XXIII r1; Gen. indet. spec. indet. XX r1; **68_{NBw}**: Gen. indet. spec. indet. XXIV r1; Gen. indet. spec. indet. XXV p4; Gen. indet. spec. indet. XXXI r1; Gen. indet. spec. indet. XXX r1

3.2.20 *Psychotria mahonii-Maesa lanceolata-Xymalos monospora* Community

Fuzzy k-means cluster number: M12
UPGMA, local cut information level: 35 % (last joint)
Plots: 16_{NG} Locations: Nyungwe, Gisovu

M12	16_{NG}	26_{NB}	71_{NM}
16_{NG}	0	0.73	0.74
26_{NB}		0	0.86
71_{NM}			0

Table 3.43: Bray-Curtis dissimilarities between the samples discussed.

M12	16_{NG}	26_{NB}	71_{NM}
16_{NG}	0	14.55	10.93
26_{NB}		0	16.41
71_{NM}			0

Table 3.44: Geographic distances between the samples discussed in km.

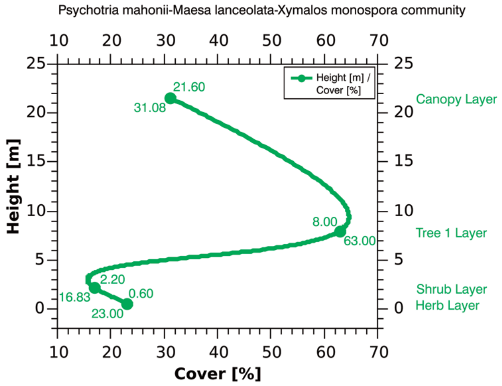

Figure 3.28: Cover-Height relation of the community recovered near Gisovu; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

The NE facing site is situated in the upper level of the montane rain forest. Its two tree layers, not exceeding 22 m, are rooted in a rather shallow sandy soil which has a pH of 3.31. Due to the insufficient drillable soil depth, the temperature could not be measured. Ground cover of the herb and shrub layer is 16% and 23, respectively.

The two plots most similar to site 16_{NG} in Nyungwe Forest around Gisovu are plot 71_{NM} near Mukura and plot 26_{NB} on Mount Bigugu. Plot 16_{NG} should not be merged to either of those. Both sample sites are well integrated into their respective cluster, which does not allow for the addition of sample site 16_{NG}. The FCM-NC and UPGMA arrive at similar solutions. Within the dendrogram derived via UPGMA, site 16_{NG} is singled out already at the 35% information level. The dendrogram further elicits that site 16_{NG} is closer to the vegetation on Mt. Bigugu, a circumstance which will be dealt with when establishing the syntaxonomy for this survey's sample sites. The sparse crown cover comprises *M. lanceolata*, *P. latifolius*, *P. mahonii*, *G. acuminata* and *S. parvifolium*. The last species is also found in a second tree layer among others with *X. monospora*. As to the assignment to an existing syntaxonomic unit, Fischer's (1996) *P. latifolius-S. parvifolium-P. mahonii* community shows quite some similarities. This vegetation unit is subsumed under primary cloud forests of the upper level. Another community not far off is the *Macaranga-Syzygium-Podocarpus* secondary forest of Fischer & Hinkel (1994). The *Macarango-Psychotrietum mahonii* established by Habiyaremye (1997) also offers some reasonable overlap. Here, Habiyaremye (ibid.) gave some explanation as to the occurrence of *P. latifolius* and *G.* which represent species also present within a primary forest. The author stated that these species, when occurring within the shrub layer, serve as indicators of a recovering primary forest (ibid., p. 120). In the sample plot at hand, at least *P. latifolius* can also be found within the canopy. Both species are present from the shrub to the second tree layer. As mentioned, at least two communities are in line as a suitable syntaxonomic unit; one of which is a primary forest the other a secondary forest. In light of Habiyaremye's (1997) remarks, it seems that the our sample holds a degraded primary forest modelled closely on the primary cloud forest described by Fischer (1996). As a working title, *P. mahonii-M. lanceolata-X. monospora* community has to suffice for the time being.

Table 3.45: *Psychotria mahonii-Maesa lanceolata-Xymalos monospora* community

Sample Site / Species	16NG
Exposition	NE
Inclination [°]	11
Position / Relief	HO
Precipitation / a [mm]	1643
Elevation a.s.l. [m]	2764
T S_{60} [°C]	n/a
pH	3.31
Soil texture	Sl
t Height [m]	21.6
t1 Height [m]	8
t2 Height [m]	n/a
t3 Height [m]	n/a
Shrub Height [m]	2.2
Herb Height [m]	0.6
Moss Height [m]	0.05
Juvenil Height [m]	n/a
Epiphyts [m/6m]	1
Vegetation Cover [Londo]	10
t Cover [%]	31.08
t1 Cover [%]	63.00
t2 Cover [%]	0
t3 Cover [%]	0
Shrub Cover [%]	16.83
Herb Cover [%]	22.99
Moss Cover [%]	n/a
Juvenil Cover [Londo]	n/a
Juvenil Shrub Cover [Londo]	n/a
Psychotria mahonii	3
Maesa lanceolata	2
Xymalos monospora	2
Syzygium parvifolium	1.2
Podocarpus latifolius	0.7
Mimulopsis cf. excellens	0.7
Maytenus acuminata	0.7
Asplenium sp. IV	0.7
Asplenium mildbraedii	0.7
Pilea rivularis	p1
Panicum sp.	p1
Impatiens gesneroidea	p1
Hypnum cupressiforme	p1
Begonia meyeri-johannis	p1
Atractylocarpus sp.	p1

Table 3.45: *Psychotria mahonii-Maesa lanceolata-Xymalos monospora* community (contin.)

Sample Site / Species	16_{NG}
Senecio cf. nyungwensis	p2
Rubus cf. steudneri	p2
Peddiea orophila	p2
Mikania cordata	p2
Galiniera saxifraga	p2
Tacazzea apiculata	p4
Vittaria reekmansii	r1
Coleus cf. autranii	r1
Sida ternata	r1
Senecio sp. III	r1
Myrsine melanophloeos	r1
Pilea sp.	r1
Pilea johnstonii	r1
Phyllanthus ovalifolius	r1
Phyllanthus nummularifolius	r1
Ipomoea involucrata	r1
Elaphoglossum sp.	r1
Dryopteris sp. XIX	r1
Asplenium cf. anisophyllum	r1

Further species in the samples: **16_{NG}**: Polypodiales sp. XIX p1; Polypodiales sp. XXI r1; Polypodiales sp. V r1; Gen. indet. spec. indet. V r1

3.2.21 *Parinari excelsa-Ocotea usambarensis-Chassalia subochreata* Community

Fuzzy k-means cluster number: M23 + M37

UPGMA, local cut information level: 80%, 72 %, 64 %

Plots: 5_{NU}, 12_{NU}, 13_{NU}, 53_{NGs} Locations: Nyungwe, Uwinka, Gasumo

M23 + M37	5_{NU}	12_{NU}	13_{NU}	53_{NGs}
5_{NU}	0	0.66	0.58	0.61
12_{NU}		0	0.58	0.79
13_{NU}			0	0.64
53_{NGs}				0

Table 3.46: Bray-Curtis dissimilarities between the samples discussed.

M23 + M37	5_{NU}	12_{NU}	13_{NU}	53_{NGs}
5_{NU}	0	0.26	0.24	14.09
12_{NU}		0	0.02	14.27
13_{NU}			0	14.26
53_{NGs}				0

Table 3.47: Geographic distances between the samples discused in km.

In this case, UPGMA and the fuzzy c-means yield somewhat different results. The fuzzy c-means–despite the 58% difference–places plots 12_{NU} and 13_{NU} in the same cluster. The dendrogram stemming from UPGMA places the plots 12_{NU} and 13_{NU} quite close to 5_{NU} and 53_{NGs}. These two plots, though joined late and only at the ~64% information level, might also be included in the same cluster. Comparing the results to the Bray-Curtis dissimilarity values, plots 5_{NU} and 13_{NU} are actually as different from each other (58%) as 12_{NU} and 13_{NU}. With 12_{NU} and 5_{NU} the difference amounts to 66% and 61% with 5_{NU} and 53_{NGs}. While 12_{NU} and 53_{NGs} differ to 79%, plots 13_{NU} and 53_{NGs} differ to 64%. The fuzzy c-means puts plot 53_{NGs} into a cluster of its own. To only a minute membership value, the noise cluster is given as a secondary cluster for site 53_{NGs}.

Most of the plots are situated within the mid-level montane rain forest; only site 53_{NGs} can be found in the lower level. The expositions range from WNW via ENE and NE to SE. Drillable soil depths span from 0.63 to 0.92 metres, while the measured temperatures range from 13.50°C to 15.10°C. The pH of the mostly sandy soils varies between 2.47 and 2.95. Except for one plot, all hold three tree layers which reach a maximum height of 29 m and cover mostly well-developed shrub layers while the herb layers are only meagre.

In terms of species occurrences, we first take a look at plots 12_{NU} and 13_{NU}. *R. kigeziensis* is a prominent member of the second and third tree layer. The crown stratum is not quite as monotonous as in most of the other sites. Though an unidentified *Rubiaceae* sp. I is dominant in plot 12_{NU}, *F. saligna* can be found in moderate abundance. Furthermore, *P. excelsa*, *C. grandiflora*, *O. usambarensis* and *S. parvifolium* are present in minor abundances. In plot 13_{NU} *O. usambarensis*, *F. saligna* and *S. parvifolium* cover the largest area. *F. laurifolia* and *O. rochetiana* can be found in little abundances. In the shrub layer of both plots, a yet unidentified species of *Tricalysia* can be found in minor to medium abundances, alternating with *C. subochreata*. Both stands belong to the medium-altitude level (2100 - 2600 m a.s.l.) of the montane forest in Nyungwe National Park (Fischer & Killmann, 2008). Lebrun & Gilbert (1954) allocated *O. usambarensis* to the order *Ficalhoo-Podocarpetalia*. Canopy height here is given with a maximum of 25 m, a little less than the 29 m of plot 12_{NU}. More important is the absence of Gymnosperms and of most other species given as characteristic for this order by the authors (ibid.). Schmitz (1988) also placed the species within this order belonging to the *Forêts denses humides de montagne*. *F. saligna*, as the codominant species, is said to transgress the order *Olea-Jasminetalia* (Lebrun & Gilbert, 1954), which itself cannot be used to characterise the vegetation at hand. An even less applicable association appears to be the *Philippietum johnstonii* Habiyaremye & Lejoly 1993. The focus has to be drawn from the dominant species towards the whole formation to reach a meaningful classification. Here, the *Carapo-Beilschmiedietum rwandensis* Habiyaremye 1993 and the *Parinaro-Ocotetum michelsonii* Habiyaremye 1993 offer quite a few similarities to the examined vegetation. An assignment to one of the associations might be a bit bold. As an example, let us consider the *Parinaro-Ocotetum michelsonii*. Here, the different *Ocotea* species might not be the main reason for the indecision, since both occupy the same niche, and *O. michelsonii* is far less frequent; the primary reason is merely species occurrences and, thus, sample size and positioning. More precisely, species distribution in contiguous patches, which may reiterate in sine wave form, within the survey area in conjunction with the sampling regime could be the origin of differing classifications. Drawing on the introductory paragraph to this section, plots 5_{NU} and 53_{NGs} might be added to the cluster at hand. This addition shifts species composition slightly towards the Parinari-Ocotetum but does not constitute an authoritative ruling. Even less so since the community should be named according to the formative species. Thus, *Parinari excelsa-Ocotea usambarensis-Chassalia subochreata* community should be an apposite denomination.

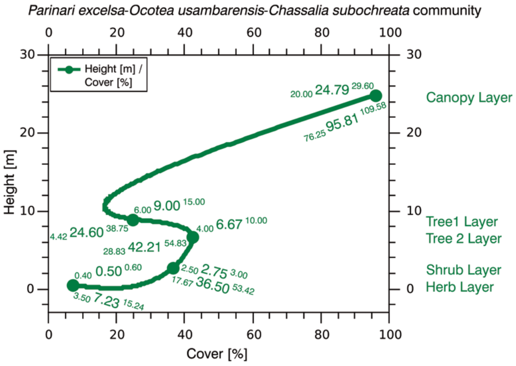

Figure 3.29: Cover-Height relation of the community recovered near Gasumo and Uwinka; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Table 3.48: *Parinari excelsa-Ocotea usambarensis-Chassalia subochreata* community

Sample Site / Species	5_{NU}	12_{NU}	13_{NU}	53_{NGs}
Exposition	WNW	NE	ENE	SE
Inclination [°]	33	42	41	31
Position / Relief	HM	HM	HM	HM
Precipitation / a [mm]	1878	1878	1878	2201
Elevation a.s.l. [m]	2396	2381	2385	1908
T S_{60} [°C]	13.50	15.10	15.10	n/a
pH	2.47	2.72	2.95	2.89
Soil texture	T(l)	Sl	Sl	Sl
t Height [m]	27.50	29.60	22.05	20.00
t1 Height [m]	5.00	15.00	6.00	9.00
t2 Height [m]	n/a	10.00	4.00	6.00
t3 Height [m]	n/a	n/a	n/a	n/a
Shrub Height [m]	2.50	3.00	2.50	3.00
Herb Height [m]	0.6	0.4	0.6	0.4
Moss Height [m]	0.002	0.05	0.02	0.005
Juvenil Height [m]	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	0	0	0	0
Vegetation Cover [Londo]	10	10	10	10
t Cover [%]	109.58	88.75	76.25	108.67
t1 Cover [%]	38.58	16.67	38.75	4.42
t2 Cover [%]	0	28.83	54.83	42.97
t3 Cover [%]	0	0	0	0
Shrub Cover [%]	34.25	53.42	40.67	17.67
Herb Cover [%]	5.42	3.50	15.42	4.58
Moss Cover [%]	3.83	1.08	<1	<1
Juvenil Cover [Londo]	a4	p4	2	a2
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	n/a
Chassalia subochreata	3	0.7	3	2
Syzygium parvifolium	1.2	1.2	1.2	r1
Carapa grandiflora	1.2	0.7	r1	2
Asplenium sp. IV	p1	p1	p1	a2
Rytigynia kigeziensis	4	2	6	
Parinari excelsa	8	0.7		4
Astropanax goetzenii	p2	2		p1
Ocotea usambarensis		1.2	5+	5+
Vittaria reekmansii		p1	p1	p1
Pyrrhobryum spiniforme	p4	r1	r1	
Fissidens sp. I	r1	p2	p1	
Faurea saligna		1.2	4	
Tricalysia sp.		4	0.7	
Beilschmiedia rwandensis		0.7	p2	
Salacia sp.		p1	r1	
Keetia gueinzii		p1	p2	
Isachne mauritiana		p1	p1	
Asplenium cf. dregeanum		r1	p1	
Olinia rochetiana	0.7		r4	
Asplenium sandersonii	r1			p1
Salacia erecta	p2			p1
Asplenium normale	p1	p2		
Asplenium mannii	r1	r1		
Sericanthe leonardii	p2	p2		
Mikaniopsis tedliei	p1	p1		
Embelia schimperi	r1			

Table 3.48: *Parinari excelsa-Ocotea usambarensis-Chassalia subochreata* community (continued)

Sample Site / Species	5NU	12NU	13NU	53NGs
Asplenium cf. erectum	r1			
Blotiella sp. I	r1			
Asplenium cf. loxoscaphoides	p1			
Asplenium loxoscaphoides	r1			
Coleus cf. melleri	r1			
cf. Teleranea sp.	r1			
Blotiella stipitata	p1			
Racopilum africanum	r1			
Coleus melleri	r1			
Asplenium mildbraedii	r1			
Tectaria sp. II	r1			
Blotiella bouxiniana	r1			
Impatiens purpureo-violacea	p1			
Asplenium erectum	p1			
Urera hypselodendron	p1			
Pavetta bagshawei		r1		
Cassipourea ndando		r1		
Tacazzea apiculata		r1		
Asplenium theciferum		r1		
Cyclodictyon sp.		r1		
Loxogramme cf. abyssinica		r1		
Anisosepalum humbertii		p1		
Asplenium aff. protensum		r1		
Asplenium sp. XXXIX		r1		
Dryopteris sp. III		p1		
Asplenium sp. VI		p1		
Ficalhoa laurifolia			p4	
Asplenium sp. II			p1	
Balthasaria schliebenii			r1	
Lasianthus kilimandscharicus			r1	
Asplenium sp. XLI			r1	
Asplenium sp. XXI			p1	
Xymalos monospora				3
Dracaena laxissima				p1
Symphonia globulifera				r1
Strombosia scheffleri				r1
Peperomia sp.				a2
Asplenium dregeanum				p1
Impatiens sp.				r1
Culcasia scandens				p1
Culcasia falcifolia				r1
Tectaria gemmifera				r1
Senegalia montigena				p2
Leucobryum madagassum				p1
Syrrhopodon sp.				p1
Arthropteris monocarpa				a1
Smilax anceps				r1
Tiliacora sp.				r1
Peperomia sp. I				p1
Octoknema sp.				r1
Asplenium burundense				p1
Psychotria cf. peduncularis				p2
Asplenium dregeanum				a1

Table 3.48: *Parinari excelsa-Ocotea usambarensis-Chassalia subochreata* community (continued)

Sample Site / Species	5_{NU}	12_{NU}	13_{NU}	53_{NGs}
Grewia sp. I				r1
Oxyanthus troupinii				p4
Oxyanthus speciosus				p2

Further species in the samples: **12**$_{NU}$: Rubiaceae sp. I: 5- ; Bryopsida sp.VII: p1; **13**$_{NU}$: Polypodiales sp.XVI: r1; Polypodiales sp.XII: r1; **53**$_{NGs}$: Gen. indet. spec. indet.CXXXVII: r1; Apocynaceae sp.V: r1

3.2.22 *Shirakiopsis elliptica* Standard Tree Secondary Forest

Fuzzy k-means cluster number: M19
UPGMA, local cut information level: 19%
Plots: 48$_{C}$ Locations: Nyungwe, Cyamudongo

This site is positioned at the lower level of the montane rain forest with a SE exposition. The drillable soil depth of 0.46 m represents the shallow end of the spectrum measured. In the sandy soil, a pH of 3.97 has been determined, and the mean annual temperature is at the upper end of the measured span at 18.25°C. Four tree strata are discernible of which the canopy reaches 34 metres. The shrub and herb layer are barely developed.

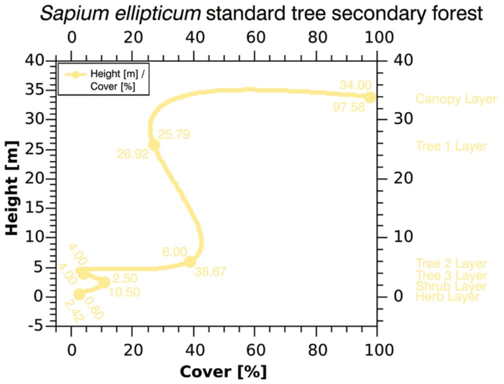

Figure 3.30: Cover-Height relation of the community recovered near Gasumo and Uwinka; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Plot 48$_{C}$, situated in Cyamudongo Forest, has been assigned to a cluster of its own by the fuzzy c-means with noise clustering. The hierarchical UPGMA method joins plot 48$_{C}$ only at the 19% information level to plots 56$_{C}$ and 57$_{C}$ with a dissimilarity of 95% and 90%, respectively. The two most similar plots, according to the BRAY-CURTIS dissimilarity index, are plot 54$_{NGs}$ (77%) and plot 69$_{NBw}$ (78%). Neither of the sites should be associated with the sample site at hand. Similarities are few with the most similar plot, 54$_{NGs}$; these are mostly based on *Shirakiopsis elliptica*, which is the only species in common with noticeable abundance.

If one compares the species compositions of the plots–notwithstanding the dissimilarity values–it is, at a first glance, quite tempting to combine plots 56$_{C}$ and 57$_{C}$. Yet, the major connection would only be established via *Shirakiopsis elliptica*, *Carapa* spec. nov., *Microcos mildbraedii* and *Celtis gomphophylla*. Neither the number nor the abundance of the species makes for a stable vegetation unit. However, the known drawback of the sampling design does not preclude the combination of the plots once sufficient data has been collected. The vertical structure acts as an indicator here. The canopy layer of plot 48$_{C}$ is more than 10 m above the canopy of both other plots. While the mean height of the second tree stratum of plots 56$_{C}$ and 57$_{C}$ is 7.5 m plot 48 reaches about 26 m.

Following HINKEL AND FISCHER (1993), the vegetation belongs to the lower cloud forest level and within this to the secondary formations. Since the most abundant species have not yet been identified, classification into the existing system would be miscarried. To separate the vegetation unit described under 3.2.37, the current unit could be named *Shirakiopsis elliptica* standard tree secondary forest as an interim solution.

Table 3.49: *Shirakiopsis elliptica* standard tree secondary forest

Sample Site / Species	69_{NBw}	54_{NGs}	56_{C}	57_{C}	48_{C}
Exposition	WSW	E	NNE	NE	SE
Inclination [°]	30	28	10	26	36
Position / Relief	HU	HM	HU/HM	HM	MH
Precipitation / a [mm]	1865	2232	1639	1639	1661
Elevation a.s.l. [m]	1915	1906	1837	1905	1798
T S_{60} [°C]	16.00	n/a	17.00	n/a	18.25
pH	3.17	3.24	3.66	5.51	3.97
Soil texture	Sl	Sl	Sl	Ls2-3	Sl
t Height [m]	20	22	21	20	34
t1 Height [m]	14	13.37	8	7	25.79
t2 Height [m]	8	4	4	4	6
t3 Height [m]	n/a	n/a	n/a	n/a	4
Shrub Height [m]	2.5	2	2.5	2.3	2.5
Herb Height [m]	1	1	1	0.7	0.6
Moss Height [m]	n/a	n/a	0.001	n/a	0.001
Juvenil Height [m]	n/a	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1	0	1
Vegetation Cover [Londo]	10	10	10	10	10
t Cover [%]	139.08	99.58	139.17	146.33	97.58
t1 Cover [%]	0.50	97.50	39.67	75.58	26.92
t2 Cover [%]	3.42	23.92	15.05	20.78	38.67
t3 Cover [%]	0	0	0	0	<1
Shrub Cover [%]	1.25	16.33	10.58	17.75	10.50
Herb Cover [%]	79.33	13.33	2.92	16.92	2.42
Moss Cover [%]	n/a	n/a	0.25	n/a	<1
Juvenil Cover [Londo]	n/a	p1	a2	2	2
Juvenil Shrub Cover [Londo]	n/a	r1	n/a	n/a	n/a
Shirakiopsis elliptica	3	4	r1	r1	3
Clerodendrum johnstonii	p1	1.2	p2		p1
Culcasia falcifolia		p1	r1	p1	r1
Allophylus pseudopaniculatus	p1	p2	r1	p1	
Carapa sp. nov.			4	2	r1
Celtis cf. gomphophylla			r1	2	p4
Tectaria gemmifera		0.7	p1	p1	
Xymalos monospora		r1		p2	r1
Entandrophragma excelsum	r1	p4		p1	
Carapa grandiflora	3	3			
Strombosia scheffleri	6	r1			
Alchornea hirtella	r1	p2			
Symphonia globulifera	r1	r1			
Piper capense	r1	p1			
Asplenium dregeanum	r1	p1			
Asplenium sp. IV	p1	p1			
Gouania longispicata	r2	r1			
Microcos mildbraedii			7		r1
Tiliacora funifera			p2		p1
Polyscias fulva	1.2			p1	
Asplenium cf. christii	r1			p1	
Rourea thomsonii		r1			r1
Astropanax abyssinicus		1.2	r1		
Lindackeria bukobensis		r1	p1		
Tabernaemontana stapfiana	r2	p4			

Table 3.49: *Shirakiopsis elliptica* standard tree secondary forest (continued)

Sample Site / Species	69_{NBw}	54_{NGs}	56_{C}	57_{C}	48_{C}
Newtonia buchananii				r1	r1
Dracaena laxissima		p1		p1	
Zanthoxylum gilletii		r1		r1	
Dracaena fragrans			0.7	2	
Lasianthus kilimandscharicus					r2
Pteris cf. preussii					a1
Heinsenia diervilleoides					p1
Fissidens sp.					p1
Tectaria sp. V					p2
Asplenium sp. XXVI					p1
Stephania cyanantha					r1
Strychnos lucens					r1
Lepisanthes senegalensis					r1
Oxyanthus cf. speciosus					r1
Pancovia sp.					p1
Drypetes sp.					r1
Gen. indet. spec. indet. LXXIV					r1
Tabernaemontana odoratissima					p1
Ehretia sp.					r1
Cola pierlotii					r2
Tricalysia niamniamensis					r1
Myrianthus holstii		7			
Bridelia brideliifolia		3			
Ficus sp. II		1.2			
cf. Shirakiopsis elliptica		1.2			
Chassalia subochreata		r1			
Parinari excellsa		r1			
Psychotria mahonii		r1			
Galiniera saxifraga		r1			
Plectranthus sp.		r1			
Oxyanthus speciosus		r1			
Alangium chinense		r1			
Asplenium sp. VI		p1			
Asplenium aff. elliottii		p1			
Asplenium sp. XIII		p1			
Cissus oliveri		r1			
Celtis gomphophylla		r2			
Antrophyum mannianum		p1			
Diplazium sp. IV		p2			
cf. Celosia elegantissima		p1			
Pteris aff. preussii		p2			
Asplenium sp. XXVII		p1			
Coccinia cf. mildbraedii		r1			
Peperomia sp. II		r1			
Loxogramme lanceolata		r1			
cf. Rutidea orientalis		p1			
Dalbergia lactea		r1			
Deinbollia kilimandscharica		r1			
Vittaria sp.		p1			
Ficus cf. ottonifolia		r1			
Oplismenus hirtellus		a4			
Celtis durandii			7		
cf. Celtis gomphophylla			0.7		

Table 3.49: *Shirakiopsis elliptica* standard tree secondary forest (continued)

Sample Site / Species	69_{NBw}	54_{NGs}	56_{C}	57_{C}	48_{C}
Asplenium mannii			r1		
Asplenium cf. dregeanum			r1		
Pleiocarpa pycnantha			p2		
Porotrichum elongatum			p1		
Clerodendrum buchananii			r1		
Asplenium sp. XXIX			r1		
Antrophyum cf. mannianum			r1		
cf. Saba comorensis			r1		
Loeseneriella africana			p2		
Gen. indet. spec. indet. CLIX			r1		
Asplenium cf. elliottii			p2		
Ficus sp. IV				9	
Croton cf. macrostachyus				4	
Pteris sp. VII				r1	
Asplenium sp. XXX				p2	
Mimulopsis runssorica				p1	
Mimulopsis solmsii	5+				
Sericostachys scandens	2				
Impatiens niamniamensis	p1				
Asplenium sp. XXXIII	p1				
Rubus sp. III	r1				
Aframomum cf. mala	p1				
Solanum terminale	r1				
Garcinia volkensii	r1				
Rytigynia cf. bagshawei var. lebrunii	r2				
Begonia meyeri-johannis	p1				
Coccinia mildbraedii	p1				
Urera trinervis	p1				
Asplenium cf. friesiorum	p1				
Apodytes dimidiata	r1				
Rubus cf. apetalus	r1				
Panicum cf. monticola	p1				
Mimulopsis arborescens	p2				
Celosia elegantissima	p1				

Further species in the samples: **48_{C}**: Gen. indet. spec. indet. LXXII 7; Gen. indet. spec. indet. CXIX 3; Gen. indet. spec. indet. LXXIII 1,2; Gen. indet. spec. indet. LXXI 1; Acanthaceae sp. II p1; Gen. indet. spec. indet. CXII r1; Rubiaceae sp. VII r1; Gen. indet. spec. indet. CXXII r1; Gen. indet. spec. indet. CXXIII r1; Gen. indet. spec. indet. LXXV p2; Gen. indet. spec. indet. LXXVI r1; Gen. indet. spec. indet. LXXVII r4; Gen. indet. spec. indet. LX p1; Gen. indet. spec. indet. CXXI r1; Poaceae sp. VI p1; **54_{NGs}**: Acanthaceae sp. p1; Woodsiaceae sp. VII p1; Gen. nov. sp. nov. r1; Gen. indet. spec. indet. CXL r1; Gen. indet. spec. indet. CXLII p1; Gen. indet. spec. indet. CXLI r1; **56_{C}**: Gen. indet. spec. indet. LXV p1; Gen. indet. spec. indet. CLIV p1; Gen. indet. spec. indet. XXXIX 0,7; Gen. indet. spec. indet. CLIII p1; Poaceae sp. p1; Gen. indet. spec. indet. CLVIII r1; Gen. indet. spec. indet. CLX r1; Gen. indet. spec. indet. CLV r1; Acanthaceae sp. IV m1; Loranthaceae sp. r1; Gen. indet. spec. indet. CLVII r1; Gen. indet. spec. indet. CLVI r2; Meliaceae sp. r1; **57_{C}**: Gen. indet. spec. indet. XXXVII 6; Gen. indet. spec. indet. LXV p4; Gen. indet. spec. indet. CLIV r1; Acanthaceae sp. V r1; Gen. indet. spec. indet. CLXVIII r1; Gen. indet. spec. indet. XII r1; Gen. indet. spec. indet. CLXVII r1; Gen. indet. spec. indet. CLXIV r1; Gen. indet. spec. indet. XLIII r1; Gen. indet. spec. indet. CLXVI r1; Gen. indet. spec. indet. XLII r1; Gen. indet. spec. indet. XLIV r1; **69_{NBw}**: Gen. indet. spec. indet. XXXVII r1; Gen. indet. spec. indet. XVI r1; Gen. indet. spec. indet. XXXIII r1; Gen. indet. spec. indet. XXXIV r1; Gen. indet. spec. indet. XXXV r1; Gen. indet. spec. indet. XI p1; Woodsiaceae sp. I 0.7; Poaceae sp. V p1

3.2.23 *Xymalos monospora-Symphonia globulifera-Myrinathus holsti* Community

Fuzzy c-means cluster number: M21 and M29
UPGMA, local cut information level: 85 % (52%)
Plots: 92_{Gw}, 58_C, 59_C Locations: Gishwati Forest, Cyamudongo Forest

M21/M29	46_{NK}	58_C	59_C	92_{Gw}
46_{NK}	0	0.89	0.92	0.54
58_C		0	0.62	0.53
59_C			0	0.75
92_{Gw}				0

Table 3.50: Bray-Curtis dissimilarities between the samples discussed.

M21/M29	46_{NK}	58_C	59_C	92_{Gw}
46_{NK}	0	48.24	48.3	78.21
58_C		0	0.12	91.56
59_C			0	91.47
92_{Gw}				0

Table 3.51: Geographic distances between the samples discused in km.

The vast height difference might cause some is due to emergent tree in the Gishwati sample. Somewhat unexpected, one plot in Cyamudongo (58_C) and one in Gishwati (92_{Gw}), with a dissimilarity of about 53%, have been grouped by UPGMA. *Chassalia subochreata* occurs in both plots in minor abundances. *Symphonia globulifera*, though not reaching more than 50% cover, dominates the tree layer. *Macaranga kilimandscharica* also occurs at both sites but only with a higher abundance in the Gishwati plot. In both plots, *Xymalos monospora* occurs from the shrub layer up into the second tallest tree layer in noticeable abundance. *Myrianthus holstii* can be found in both sites in the tree layer in moderate abundance.

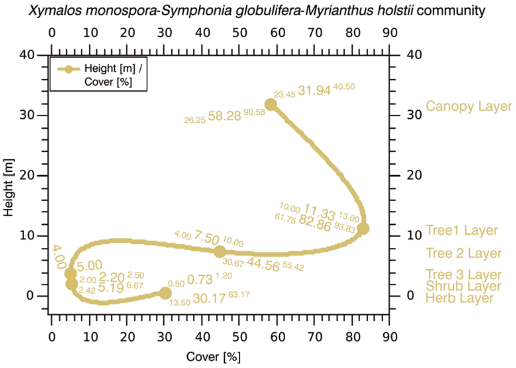

Figure 3.31: Cover-Height relation of the community recovered in Gishwati Forest and Cyamudongo Forest; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

The secondary character of the vegetation cannot be disavowed. *Xymalos monospora*, *Myrianthus holstii* and *Macaranga kilimandscharica* are the most salient species in this respect. When it comes to classification, Polyscietalia fulvae seems to be the order of choice.[1] Regarding the discussion of the classification of *Symphonia globulifera* dominated stands, the section dealing with cluster M22 § 3.2.27 should be read. Fischer & Hinkel (1994) described a *Macaranga-Symphonia* secondary forest from Gishwati. Though not all species have been found and the abundance of *Macaranga* do not yield for dominance, an assignment to this forest type seems possible. In conclusion, a community belonging to the Polyscietalia fulvae – *Xymalos monospora-Symphonia globulifera-Myrianthus holstii* – should give sufficient information as to the character of the vegetation.

The fuzzy c-means, on the other hand, splits this cluster up and joins the plots with other sites in two new clusters. Plots 92_{Gw} and 46_{NK} are combined in one cluster, and plot 58_C is assigned with plot 59_C to a second cluster. While the plots 46_{NK} and 92_{Gw} are dissimilar to about 54% according to the Bray-Curtis index, the plots 58_C and 59_C differ to 62%. Examining cluster M21 (46_{NK}, 92_{Gw}), a shift in dominance is noticeable, *S. globulifera* withdraws and is replaced by *Syzygium parvifolium* in plot 46_{NK}. It has to be mentioned that in this case the main abundances of *S. parvifolium* and *M. kilimandscharica* are found

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[1] Although exclusively cited, Lebrun & Gilbert (1954) never listed Xymalos monospora within this order. The earliest mention of Xymalos in the respective order has been found in Lewalle (1972, p. 109) without any citation.

in the second tallest tree stratum. Plot 58_C has been allotted to cluster M35. As a secondary membership, both plots (58_C, 59_C) of this cluster belong, although only to a minute share, to the noise cluster. Here, due to the altered abundances, a higher emphasis is put on *S. globulifera* while *X. monospora* and *M. holstii* are less prominent. Combining cluster M11 and M35 would make the resulting group quite heterogeneous with plot 46_{NK} being dissimilar to plots 58_C and 59_C to about 90%. The distance is also reflected in the UPGMA dendrogram within which plot 46_{NK} is jointed only at the 20% information level. As a preliminary solution, 58_C, 59_C and 92_{Gw} will be combined into one cluster. Thus, the community name proposed above can be maintained.

The sites in Cyamudongo Forest are situated in the lower level of the montane cloud forest while the site in Gishwati Forest just reaches the mid-level. While site 59_C faces north, the other two face SW and SSW, respectively. Two of the soils are sandy, one of the sites (59_C) has a clay dominated soil. This site then has the most acid soil with a pH of 3.04, while the pH of the other sites reaches 3.39 and 3.82 respectively. Mean annual temperature varies between 16°C and 17°C, while the drillable soil depth varies to around 0.50 m. In all plots, three tree layers are present, while the canopy height varies greatly; it reaches its maximum in site 58_C with $\sim$32 m and only reaches 13 m in the Gishwati site. In all sites, the shrub cover is scarce, while the herb cover is just over 10% in the Cyamudongo sites and reaches more than 60% in the Gishwati sites.

Table 3.52: *Xymalos monospora-Symphonia globulifera-Myrinathus holstii* community

Sample Site / Species	58_{C}	59_{C}	92_{Gw}	46_{NK}
Exposition	SW	N	SSW	NNW
Inclination [°]	42.00	40.00	14.00	34.50
Position / Relief	HM	HO	KH	HU
Precipitation / a [mm]	1623	1623	1365	1633
Elevation a.s.l. [m]	2005	2018	2241	2233
T S_{60} [°C]	16<16.5	17.00	15.70	14.00
pH	3.39	3.04	3.82	3.53
Soil texture	Sl	Ts	Su	Sl
t Height [m]	31.86	23.45	13	30.74
t1 Height [m]	11	n/a	10	9
t2 Height [m]	6.00	6.50	4.00	n/a
t3 Height [m]	n/a	n/a	n/a	n/a
Shrub Height [m]	2.00	2.50	2.10	2.50
Herb Height [m]	0.50	0.50	1.20	0.50
Moss Height [m]	n/a	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	1	0	1	0
Vegetation Cover [Londo]	10	10	10	10
t Cover [%]	90.58	58.00	119.25	13.33
t1 Cover [%]	93.83	61.75	55.42	132.05
t2 Cover [%]	47.58	30.67	5.00	0
t3 Cover [%]	0	0	0	0
Shrub Cover [%]	6.50	6.67	2.42	0.92
Herb Cover [%]	13.50	13.83	63.17	32.25
Moss Cover [%]	n/a	n/a	n/a	n/a
Juvenil Cover [Londo]	0.7	a2	p2	a1
Juvenil Shrub Cover [Londo]	n	p2	p1	n/a
Xymalos monospora	2	1.2	6	5-
Chassalia subochreata	p4	r1	p2	r1
Symphonia globulifera	5	7	3	
Macaranga kilimandscharica	r1		4	4
Myrianthus holstii	4	p2	3	
Asplenium sp. IV	a2	a4		p1
Polyscias fulva	r1			r2
Asplenium cf. friesiorum			p4	p1
Asplenium sp. VI	p1		p1	
Loxogramme abyssinica	r1		p1	
Tabernaemontana stapfiana	3		2	
Carapa sp. nov.	p4	p4		
Senegalia montigena	p1	p4		
Asplenium sp. XXXI	p1	p1		
Peperomia sp. III	p1	p2		
Diplazium sp. VII	p1	0.7		
cf. Diplazium sp.	p1	p1		
Albizia gummifera	r1	r2		
Syzygium parvifolium				4
Isachne mauritiana				3
Ilex mitis				0.7
Dichanthelium hillebrandianum				0.7
Embelia schimperi				p1
Allophylus chaunostachys				p2
Galiniera saxifraga				p2

Table 3.52: *Xymalos monospora-Symphonia globulifera-Myrinathus holstii* community (continued)

Sample Site / Species	58_C	59_C	92_{Gw}	46_{NK}
Keetia gueinzii				p1
Triumfetta cordifolia				a1
Asplenium mildbraedii				p1
Phyllanthus nummularifolius				p1
Ipomoea involucrata				p1
Senecio maranguensis				p4
Otiophora pauciflora ssp. burttii				r1
Rubus cf. apetalus				r1
cf. Virectaria major				r1
Virectaria major				p1
Rubus cf. pinnatus				r1
Embelia sp.				r1
Rytigynia sp. V				r1
Cyperus renschii				m1
Kalanchoe crenata				p1
Drynaria volkensii				p1
Mikania chenopodiifolia				p1
Celosia sp. II			6	
Asplenium sp. XVI			p1	
Englerophytum rwandense			p1	
Gynura sp.			p1	
Mikaniopsis sp. III			p1	
Cucumis sp. II			p1	
Adenia cf. bequaertii			r1	
Harpagocarpus snowdenii			p1	
Pupalia sp.			r1	
cf. Clutia abyssinica			r1	
Plectranthus sp. I			r1	
Dracaena laxissima			p1	
Pilea rivularis			p1	
Gynura scandens			r1	
Astropanax goetzenii			p2	
Asplenium mannii			m1	
Oxyanthus speciosus	5-			
Alangium chinense	2			
Tabernaemontana cf. stapfiana	1.2			
Oxyanthus troupinii	r1			
Sericostachys scandens	r1			
Clerodendrum johnstonii	p2			
Elatostema monticola	p1			
Piper capense	r1			
Keetia sp. I	r1			
Asplenium cf. sandersonii	p1			
Entandrophragma excelsum	r2			
Culcasia falcifolia	r1			
Adenia sp.	p1			
Drypetes gerrardii	r1			
Tectaria gemmifera	a2			
Dalbergia lactea	r1			
Astropanax abyssinicus	p1			
Dryopteris sp. XVIII	a4			
Pteris cf. pteridioides	a1			
Asplenium sp. XII	r1			

Table 3.52: *Xymalos monospora-Symphonia globulifera-Myrinathus holstii* community (continued)

Sample Site / Species	58_{C}	59_{C}	92_{Gw}	46_{NK}
Asplenium sp. XVIII	p1			
Strychnos sp.	r1			
Agelaea pentagyna		4		
Oxyanthus cf. troupinii		2		
Gambeya gorungosana		0.7		
Peddiea fischeri		r1		
Psychotria peduncularis		r1		
Asplenium sandersonii		p1		
Parinari excellsa		r1		
Dryopteris sp. XII		p1		
cf. Spermacoce princeae				p1

Further species in the samples: **46_{NK}**: Gen. indet. spec. indet. CVIII r1; Caryophyllaceae sp. II p1; Poaceae sp. VI a1; Gen. indet. spec. indet. CIX p1; Gen. indet. spec. indet. CX r1; **58_{C}**: Araceae sp. p1; Gen. indet. spec. indet. CLXIV r1; Gen. indet. spec. indet. CLXIX p1; Gen. indet. spec. indet. CLXX r1; Gen. indet. spec. indet. CLXXI r1; Gen. indet. spec. indet. CLXXII r1; Gen. indet. spec. indet. XLV r2; Fabaceae sp. p1; **59_{C}** : Araceae sp. p1; Gen. indet. spec. indet. LXVI r1; Polypodiales sp. XXII p1; Gen. indet. spec. indet. CLXXIII r1; Gen. indet. spec. indet. CLXXIV r2; **92_{Gw}**: Gen. indet. spec. indet. VIII r1; Euphorbiaceae sp. I r1; Gen. indet. spec. indet. X p1

3.2.24 *Xymalos monospora-Macaranga-Isachne mauritiana* Community

Fuzzy k-means cluster number: M21.1
UPGMA, local cut information level: 66 %
Plots: 46_{NK} Locations: Nyungwe, Kitabi

Species combination within site 46_{NK} has some remarkable similarities to the just described *Isache mauritiana* dominated 3.2.13 community. The description of the vegetation can be taken in part from the preceding paragraph and from Table 3.52 Some further similarities, at least with the Macarango-Psychotrietum mahonii, add to the ambiguity with which the site at Kitabi is set aside as a single community. These similarities shall be reflected on a higher syntaxonomic level and elaborated in the consecutive chapter (3.3.9).

The decision to exclude the plot from the preceding community has been taken by virtue of the arbitrariness of one's own. Upon closer examination, it could also be justified to break up the previously established cluster and create two new ones, consequently keeping Gishwati Forest from having a connection to the eastern part of Nyungwe Forest. The main reason for the complications is the canopy height. The plots in Gishwati Forest leave no doubt as to their belonging to the short-stemmed forests described by Fischer & Hinkel (1994); alone plot 34_{NK} might border on the standard tree forests. The three vegetation strata in Gishwati Forest, compared to the two strata in Nyungwe Forest would add to an eventual justification for a new configuration of the communities at hand. Considering that *Maesa* is missing and *Isachne mauritiana* occurs with considerably less abundance allows for some doubt on a possible assignment;[2] however, these factors are not reason enough on their own. Only the height of the canopy makes it indispensable to separate the stand at Kitabi from the other sites.

Since *Xymalos monospora* is the dominant species in this plot, the vegetation – as preliminary as it may be – cannot be named like the community above by just adding the name adjunct '*standard tree version*'. The equal occurrence of *Macaranga* and *Syzygium* will be dealt with in anticipation of a higher syntaxonomy and, thus, in favour of *Macaranga kilimandscharica*. As a result, the *Xymalos monospora-Macaranga-Isachne mauritiana* community shall be the working title encompassing the vegetation specificity of this site.

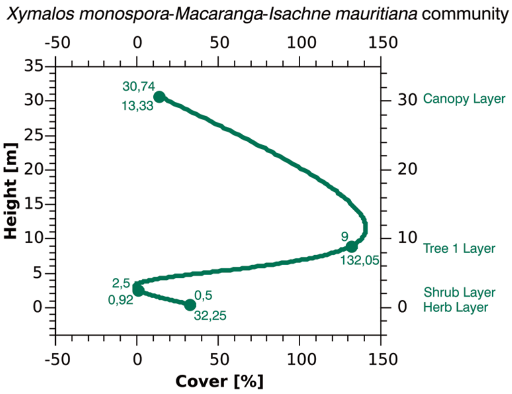

Figure 3.32: Cover-Height relation of the community recovered at Kitabi; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

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[2] In virtue of a generally less developed herb layer in plot 46_{NK}, the decreased abundance of *Isachne* may be relativised since the prevalence of the species is still given. As to the reason for the less developed herb layer, one might speculate that the very well developed second tree stratum of 9 m in height might shade the ground sufficiently as to hinder an extensive herb layer.

3.2.25 *Newtonia-Parinari* Secondary Forest

Fuzzy c-means cluster number: Noise / Noise 1
UPGMA, local cut information level: 52% (55C); 33% (58C)
Plots: 47C
Locations: Cyamudongo Forest

N1	47_C	55_C	58_C	59_C
47_C	0	0.75	0.76	0.85
55_C		0	0.76	0.96
58_C			0	0.62
59_C				0

Table 3.53: Bray-Curtis dissimilarities between the samples discussed.

N1	47_C	55_C	58_C	59_C
47_C	0	0.63	2	1.9
55_C		0	2.6	2.5
58_C			0	0.12
59_C				0

Table 3.54: Geographic distances between the samples discussed in km.

As with most sample sites from Cyamudongo, which either form a cluster as a single plot, are in the noise cluster or form clusters only with other plots from Cyamudongo, this holds true for plot 47_C. Plot 47_C has been placed within the noise cluster. The most similar plot, 55_C, only exhibits a similarity of about 25%. According to FCM-NC, the secondary membership of plot 47_C lies within cluster M29, which is constituted by plot 58_C and 59_C. The UPGMA algorithm joined plot 55_C and 47_C at the 52% information level while plot 58_C is only jointed at the 33% information level of the dendrogram. Since both plots, 58_C and 59_C, are firmly integrated into the cluster described before, merging plot 47_C would not improve the categorisation. Even though plot 55_C is quite dissimilar to plot 47_C, a combination of both might have been possible. If one takes a look at the vertical structure, then such a merging would not be well-founded. Though the stratification into three tree layers is a joint feature, the canopy of plot 55_C is by far exceeded by the one of plot 47_C. At first glance, both plots are quite in alignment with what Fischer & Hinkel (1993) entitled *Newtonia-Parinari* secondary forest, placing them into the standard tree secondary forests (Hochstämmige Sekundärwälder). This denomination does not hold for the vegetation of plot 55_C. Thus, both Cyamudongo plots will not be combined. Site 47_C will, therefore, be allotted to the vegetation unit established by Fischer & Hinkel (1993).

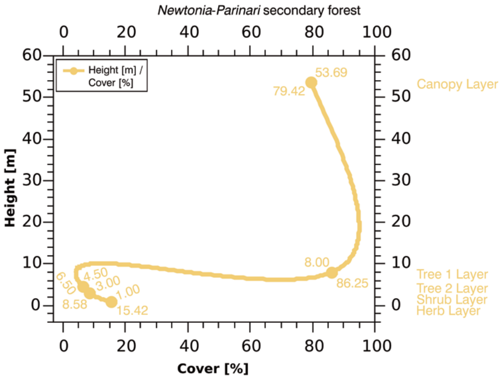

Figure 3.33: Cover-Height relation of the community recovered in Cyamudongo Forest; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Situated at the lower level of the montane cloud forest the site faces to the SSE. The loamy soil has a pH of 4.20 and points to a mean annual temperature of 15.90°C. The canopy reaches more than 50 m in height and also covers a shrub and a herb layer which are not very well developed.

Table 3.55: *Newtonia-Parinari* secondary forest Fischer & Hinkel (1993)

Sample Site / Species	47_{C}	55_{C}	58_{C}	59_{C}
Exposition	SSE	NNW	SW	N
Inclination [°]	12	20	42	40
Position / Relief	KH	HU	HM	HO
Precipitation / a [mm]	1649	1655	1623	1623
Elevation a.s.l. [m]	2041	1906	2005	2018
T S_{60} [°C]	15.90	n/a	16.25	17.00
pH	4.20	4.00	3.39	3.04
Soil texture	Ls4	Sl	Sl	Ts
t Height [m]	53.69	11	31.86	23.45
t1 Height [m]	8	8	11	n/a
t2 Height [m]	4.5	5	6	6.5
t3 Height [m]	n/a	n/a	n/a	n/a
Shrub Height [m]	3	3	2	2.5
Herb Height [m]	1	1	0.5	0.5
Moss Height [m]	n/a	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1	0
Vegetation Cover [Londo]	10	10	10	10
t Cover [%]	79.42	170.67	90.58	58.00
t1 Cover [%]	86.25	40.83	93.83	61.75
t2 Cover [%]	6.5	17.67	47.58	30.67
t3 Cover [%]	0	0	0	0
Shrub Cover [%]	8.58335	35.5	6.5	6.67
Herb Cover [%]	15.42	44.08	13.5	13.83
Moss Cover [%]	0	0	0	0
Juvenil Cover [Londo]	0.7	4	0.7	a2
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	p2
Symphonia globulifera	1.2	r1	5	7
Myrianthus holstii	p2	3	4	p2
Carapa sp. nov.	0.7	1.2	p4	p4
Alangium chinense	2	5-	2	
Xymalos monospora	p4		2	1.2
Chassalia subochreata	p4		p4	r1
Asplenium sp. IV	p1		a2	a4
Senegalia montigena		r2	p1	p4
Parinari excellsa	3			r1
Psychotria peduncularis	0.7			r1
Entandrophragma excelsum	p4		r2	
Polyscias fulva	r1		r1	
Clerodendrum johnstonii	p1		p2	
Asplenium sp. VI	r1		p1	
Diplazium sp. VII			p1	0.7
Albizia gummifera			r1	r2
Asplenium sp. XXXI			p1	p1
Peperomia sp. III			p1	p2
cf. Diplazium sp.			p1	p1
Newtonia buchananii	5+	2		
Shirakiopsis elliptica	1.2	r1		
Celtis gomphophylla	p1	p4		
Asplenium dregeanum	p1	p1		
Tectaria gemmifera		p1	a2	
Sericostachys scandens		p1	r1	
Oxyanthus troupinii		p4	r1	

Table 3.55: *Newtonia-Parinari* secondary forest Fischer & Hinkel (1993) (continued)

Sample Site / Species	47_{C}	55_{C}	58_{C}	59_{C}
Loxogramme abyssinica		r1	r1	
Strombosia scheffleri	1.2			
Zanthoxylum cf. mildbraedii	0.7			
Dalbergia cf. lactea	0.7			
Dracaena laxissima	p1			
Pteris cf. preussii	a2			
Tiliacora funifera	r1			
Gouania longispicata	r1			
Lasianthus kilimandscharicus	r1			
Cassipourea ndando	r1			
Asplenium erectum	a2			
Asplenium aff. elliottii	p1			
Dryopteris sp. XVI	a2			
Asplenium sp. XXV	p1			
Adenia sp. I	r1			
Cissus oliveri	p1			
Brachystephanus sp.	r1			
Celosia elegantissima	p1			
Culcasia scandens	p1			
cf. Piper sp.	p1			
Asplenium sp. XXIII	r1			
Scadoxus multiflorus	r1			
Toddalia asiatica	r1			
Ekebergia capensis	r1			
cf. Ancylobothrys sp.	r1			
Heinsenia diervilleoides	r2			
Elaeodendron sp.	r2			
Hylodesmum repandum	p1			
Ficus sur		8		
Neoboutonia macrocalyx		2		
Thunbergia sp.		2		
Illigera pentaphylla		r1		
Ficus asperifolia		r1		
Clausena anisata		r1		
Pteris cf. catoptera		p1		
Rutidea orientalis		r1		
Smilax anceps		r1		
Pteris aff. preussii		r1		
Allophylus pseudopaniculatus		p2		
Sclerochiton vogelii		p1		
Aframomum sp.		p1		
Cissus sp.		p1		
cf. Celtis gomphophylla		p2		
Vangueria sp.		r1		
Illigera cf. pentaphylla		r1		
Landolphia buchananii		r1		
Ficus sp. V		r4		
Mussaenda sp.		r1		
Oxyanthus speciosus			5-	
Tabernaemontana stapfiana			3	
Tabernaemontana cf. stapfiana			1.2	
Piper capense			r1	
Culcasia falcifolia			r1	

Table 3.55: *Newtonia-Parinari* secondary forest Fischer & Hinkel (1993) (continued)

Sample Site / Species	47_C	55_C	58_C	59_C
Macaranga kilimandscharica			r1	
Elatostema monticola			p1	
Keetia sp. I			r1	
Asplenium cf. sandersonii			p1	
Adenia sp.			p1	
Drypetes gerrardii			r1	
Dalbergia lactea			r1	
Astropanax abyssinicus			p1	
Dryopteris sp. XVIII			a4	
Pteris cf. pteridioides			a1	
Asplenium sp. XII			r1	
Asplenium sp. XVIII			p1	
Strychnos sp.			r1	
Agelaea pentagyna				4
Oxyanthus cf. troupinii				2
Gambeya gorungosana				0.7
Peddiea fischeri				r1
Asplenium sandersonii				p1
Dryopteris sp. XII				p1

Further species in the samples: **47_C**: Gen. indet. spec. indet. CXI p1; Gen. indet. spec. indet. CXIV r1; Gen. indet. spec. indet. CXIII r1; Gen. indet. spec. indet. CXV r1; Gen. indet. spec. indet. LXXXVIII r2; Gen. indet. spec. indet. XXVIII r1; Gen. indet. spec. indet. XXIX r1; Poaceae sp. VI p1; **55_C**: Gen. indet. spec. indet. CXLIV 0,7; Gen. indet. spec. indet. CLII 0,7; Gen. indet. spec. indet. CXLIII r1; Gen. indet. spec. indet. CLXI r1; Cucurbitaceae sp. II p1; Gen. indet. spec. indet. CLI r1; Asteraceae sp. II r1; Gen. indet. spec. indet. CLXIII r1; Gen. indet. spec. indet. CLXII r1; Gen. indet. spec. indet. CXLVI r1; Gen. indet. spec. indet. CXLVII r1; Gen. indet. spec. indet. CL r1; Gen. indet. spec. indet. CXLIX r1; Gen. indet. spec. indet. XXXVI p2; Gen. indet. spec. indet. LXIV r1; **58_C** : Araceae sp. p1; Gen. indet. spec. indet. CLXIV r1; Gen. indet. spec. indet. CLXIX p1; Gen. indet. spec. indet. CLXX r1; Gen. indet. spec. indet. CLXXI r1; Gen. indet. spec. indet. CLXXII r1; Gen. indet. spec. indet. XLV r2; Fabaceae sp. p1; **59_C** : Araceae sp. p1; Gen. indet. spec. indet. CLXXIII r1; Gen. indet. spec. indet. CLXXIV r2; Gen. indet. spec. indet. LXVI r1; Polypodiales sp. XXII p1

3.2.26 *Newtonia-Parinari* Secondary Forest (low-stemmed variant)

Fuzzy c-means cluster number: M9
UPGMA, local cut information level: 52% (47_C); 33% (58_C)
Plots: 55_C
Locations: Cyamudongo Forest

M9	47_C	51_C	55_C	58_C
47_C	0	0.83	0.75	0.76
51_C		0	0.75	0.86
55_C			0	0.76
58_C				0

Table 3.56: Bray-Curtis dissimilarities between the samples discussed.

M9	47_C	51_C	55_C	58_C
47_C	0	10.67	0.63	1.99
51_C		0	10.23	11.70
55_C			0	2.60
58_C				0

Table 3.57: Geographic distances between the samples discused in km.

The prevalence of *Ficus sur* in site 55_C does not facilitate a classification into the existing system. According to HAMILTON & BENSTED-SMITH (1990) *F. sur* is a steady and common sight in secondary montane forests, at least in the Usambara Mountains. Species composition, as has been written previously, is quite in accordance with the *Newtonia-Parinari* secondary forest (FISCHER & HINKEL, 1993). Only the height of the canopy prevents a categorisation into this unit. Since no fallen tree or any sign of individual tree removal has been found, the elusive history of this vegetation patch does not reveal any evidence on which subsumption could be justified. The alternative low-stemmed secondary forest (Niedrigstämmige Sekundärwälder), especially the *Carapa grandiflora-Symphonia* secondary forest, does not convince on the aspect of species composition. Therefore, on a preliminary basis, a low-stemmed variant of the *Newtonia-Parinari* secondary forest will be fabricated here. The author will refrain from further clustering approaches with the next similar plots due to the high dissimilarity values and the discussions on vegetation composition in the two previous paragraphs.

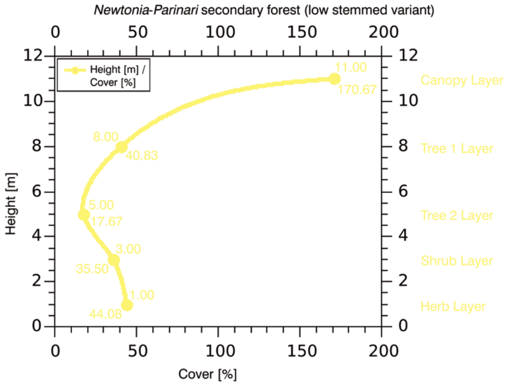

Figure 3.34: Cover-Height relation of the community recovered in Cyamudongo Forest; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

The NNW facing site is positioned at the lower level of the montane cloud forest. The drillable soil depth, pH and temperature of the sandy soil could not be determined. The somewhat discernible three tree layers cover a shrub layer and a herb layer which are quite well developed.

3.2.27 *Symphonia globulifera-Strombosia scheffleri-Measa lanceolata* Community

Fuzzy k-means cluster number: M22
UPGMA, local cut information level: 95%
Plots: 84_{Gw}, 88_{Gw} Location: Gishwati forest

Dissimilarity (Bray-Curtis): 0.45 Distance [km]: 0.52

Symphonia globulifera dominates the tree layer in two of the plots surveyed in Gishwati Forest. Both plots, being only 520 m apart, show quite similar vegetation within the canopy layer. This stratum stands out 25 metres above the ground and covers two more tree layers as well as a shrub and a herb layer, which are barely developed. The sandy soil has a pH of 3.70 and 3.55, respectively. The drillable soil depth of the sandy soils varies between 0.76 and 0.36 m. The mean annual temperature of the S and SW facing sites is about 15°C.

The fuzzy c-means and UPGMA (local cut at 95% information level) group both plots into one cluster despite the 45% dissimilarity according to the Bray-Curtis index. *Macaranga kilimandscharica* is present in both plots as regrowth in the second and third tree layer, respectively. Within the second tree layer, *Maesa lanceolata* is predominant at least in plot 88_{Gw}. *Strombosia scheffleri* occurs in both plots and can be found in the second and in the tallest tree layer covering about 46% to 55% of the area, respectively.

Although not all the tree species characterising Fischer & Hinkel's (1994) *Carapa grandiflora-Croton macrostachyus-Symphonia* secondary forest were found, species composition allows for an assignment of the two plots to this community (cf. Tab**. 3.58 & T**ab. 8 in Fischer & Hinkel (1994, p. 60). Following Habiyaremye (1997), the community found has to be classified as *Ficalhoo-Podocarpetalia*. Here, Habiyaremye (1997) referred to Lebrun & Gilbert (1954) and their work "Une classification ècologique des forêst du Congo" within which such a classification could not be found by the author. Instead, Lebrun & Gilbert (1954) placed *Symphonia globulifera* in "Les forêts édaphiques liées aux sols hydromorphes" more precisely, into the order Mitragyno-Raphietalia Schnell 1952. The ecological conditions at the sites in Gishwati Forest do not correspond in the least to those necessary for the communities of said order. It is understood that species composition of the community found does not parallel in the least to the inventory of the order mentioned. Schmitz (1988) classified forests with *Strombosia scheffleri* as predominant species within "Les forest dense climaciques," and here into the class Strombosio-Parinarietea Lebrun & Gilbert 1954. This is the only class Lebrun & Gilbert proposed to be used (ibid., p.12) for ombrophilous indeciduous forests within their survey area. Further classification into the existing system is rendered impossible without overstretching the boundaries of good scientific conduct. In conclusion, the classification of Fischer & Hinkel (1994) is best suited to comprise the vegetation of the two plots. A sub-

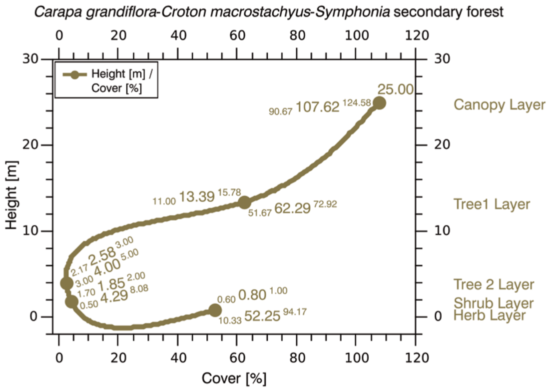

Figure 3.35: Cover-Height relation of the community recovered in Gishwati Forest; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

division highlighting the heightened *Strombosia* proportion and emphasising the differences within the herb layer, e.g., *Justicia sp.*, *Piper capense*, *Pteris* cf. *pteridioides*, necessitates further field-work. As a preliminary denomination, the *Symphonia globulifera*-*Strombosia scheffleri*-*Maesa lanceolata* community could be established as well.

Table 3.58: *Symphonia globulifera-Strombosia scheffleri-Measa lanceolata* community

Sample Site / Species	84_{Gw}	88_{Gw}
Exposition	S	SW
Inclination [°]	30	40
Position / Relief	HO	HM
Precipitation / a [mm]	1357	1363
Elevation a.s.l. [m]	2322	2226
T S_{60} [°C]	15.30	14.50
pH	3.70	3.55
Soil texture	Sl	Sl
t Height [m]	25	25
t1 Height [m]	11	15.78
t2 Height [m]	3	5
t3 Height [m]	n/a	n/a
Shrub Height [m]	1.7	2
Herb Height [m]	0.6	1
Moss Height [m]	n/a	n/a
Juvenil Height [m]	n/a	n/a
Epiphyts [m/6m]	0	1
Vegetation Cover [Londo]	10	10
t Cover [%]	90.67	124.58
t1 Cover [%]	51.67	72.92
t2 Cover [%]	2.17	3.00
t3 Cover [%]	0	0
Shrub Cover [%]	0.50	8.08
Herb Cover [%]	94.17	10.33
Moss Cover [%]	n/a	n/a
Juvenil Cover [Londo]	p1	p1
Juvenil Shrub Cover [Londo]	p1	p1
Symphonia globulifera	5-	8
Strombosia scheffleri	6	5-
Macaranga kilimandscharica	2	r1
Maesa lanceolata	p4	5+
Pteris cf. pteridioides	p1	p1
Ipomoea sp.	p1	r1
Thalictrum rhynchocarpum	p1	
Psychotria mahonii	r1	
Allophylus chaunostachys	r1	
Neoboutonia macrocalyx	2	
Phyllanthus nummularifolius	p1	
cf. Mondia aff. whitei	p1	
Psychotria cf. mahonii	r1	
Gambeya gorungosana	p1	
Dombeya torrida	r1	
Adenochloa cf. claytonii	p1	
Justicia sp.	9	
Impatiens stuhlmannii	p1	
Acanthopale sp.	p1	
Pteris sp. IV	p1	
Diplazium sp. II		r1
Momordica sp.		p2
Diplazium sp. I		p4
Tectaria sp. I		p1
cf. Hypolepis goetzenii		p1

Table 3.58: *Symphonia globulifera-Strombosia scheffleri-Measa lanceolata* community (cont.)

Sample Site / Species	84_{Gw}	88_{Gw}
Pilea rivularis		p1
Rotheca bukobensis		r1
cf. Sericostachys sp.		p2
Sericostachys sp.		p2
Sericostachys sp. I		p4
Tectaria cf. coadunata		p1
Clerodendrum johnstonii		p1
Myrianthus holstii		1.2
Piper capense		0.7
Asplenium cf. friesiorum		p2
Chassalia subochreata		p2
Pteris cf. preussii		r1
Gouania longispicata		p1
Culcasia falcifolia		r1

Further species in the samples: **84_{Gw}**: Polypodiales sp. I r1 ; Cucurbitaceae sp. XII r1; Gen. indet. spec. indet. CXCIII p1; Gen. indet. spec. indet. LVII p1; Acanthaceae sp. VIII p1; Polypodiales sp. II r1; Cucurbitaceae sp. XVIII r1; Gen. indet. spec. indet. CXCIV r1; Cucurbitaceae sp. XIX r1; **88_{Gw}**: Polypodiales sp. I r1; Cucurbitaceae sp. XXI r1; Gen. indet. spec. indet. CXXVI r1; Gen. indet. spec. indet. LXIX p1; Acanthaceae sp. XIII r1; Gen. indet. spec. indet. LV r1; Polypodiales sp. VI r1; Gen. indet. spec. indet. LXIII p2

3.2.28 *Macaranga kilimandscharica* Dominated Secondary Community

Fuzzy k-means cluster number: M28.1

UPGMA, local cut information level: 76 % , incl. 70_{NM}: 67 %

Plots: 33_{NGa}, 43_{NK}, 44_{NK}, 61_{NR} , 70_{NM}, 75_{NM}, 83_{Gw}, 91_{Gw}

Locations: Nyungwe, Kitabi, Musebeya

M28	33_{NGa}	43_{NK}	44_{NK}	61_{NR}	70_{NM}	75_{NM}	83_{Gw}	91_{Gw}
33_{NGa}	0	0.45	0.5	0.57	0.61	0.53	0.54	0.59
43_{NK}		0	0.55	0.66	0.75	0.61	0.58	0.64
44_{NK}			0	0.67	0.62	0.51	0.59	0.65
61_{NR}				0	0.77	0.7	0.68	0.7
70_{NM}					0	0.65	0.71	0.68
75_{NM}						0	0.62	0.6
83_{Gw}							0	0.42
91_{Gw}								0

Table 3.59: Bray-Curtis dissimilarities between the samples discussed.

M28	33_{NGa}	43_{NK}	44_{NK}	61_{NR}	70_{NM}	75_{NM}	83_{Gw}	91_{Gw}
33_{NGa}	0	12.31	12.04	35.08	30.55	31.01	92.08	90.69
43_{NK}		0	1.64	23.59	18.25	18.71	79.81	78.40
44_{NK}			0	24.66	18.79	19.23	80.06	78.69
61_{NR}				0	9.64	9.70	60.74	59.06
70_{NM}					0	0.51	61.81	60.35
75_{NM}						0	61.32	59.86
83_{Gw}							0	2.07
91_{Gw}								0

Table 3.60: Geographic distances between the samples discused in km.

With the exception of two N facing sites, the exposition of the respective sites is towards SE to SW. All of them are positioned at the mid-level of the montane rain forest on shallow to moderately deep soils with pH values varying between 2.63 and 3.22. In most cases, the soil texture is sandy, and in three cases, the clay fraction dominates. The mean annual temperature can get as low as 13.50°C and does not exceed 15.00°C. Most of the sites harbour three tree layers, while in two sites, only two layers are visible. The ground coverage of the shrub layer varies from barely existent to about half of the sample site, and the same is valid for the herb layer, although here the highest cover exceeds 60%.

With a local cut at about the 76% information level, UPGMA gives a result quite similar to the solution derived by FCM-NC. Seemingly, all six plots have been grouped into one cluster by both methods. We shall see if that really is the case and should be maintained.

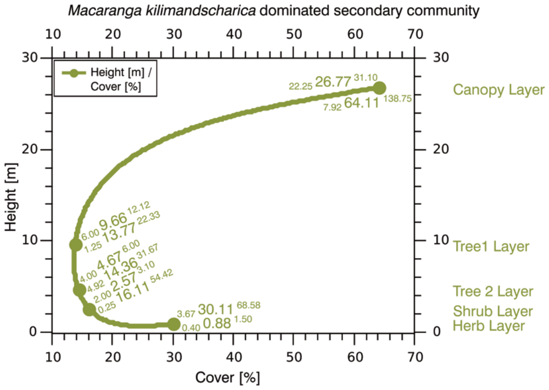

Figure 3.36: Cover-Height relation of the community recovered in Nyungwe Forest; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Southward from Musebeya towards Kitabi and Gahurizo, vegetation character changes slightly. *Macaranga kilimandscharica* is still the main unifying species in the upper tree layer, but species composition tends more towards what Fischer & Hinkel (1994) called “Hochstämmige Sekundärwälder” (standard tree secondary forests) approximating the *Macaranga-Allophylus abyssinicus* secondary forest – approximating only since *A. abyssinicus* has not been found. *Allophylus chaunostachys* has been found instead, however, only in minor abundance. *Polyscias fulva* occurs in only one plot as does *Neoboutonia macrocalyx* and *Coccinia mildbraedii*. Far more compelling, though less precise, is the classification into Habiyaremye’s (1997) *Macarango-Psychotrietum mahonii*. However, it should be noted that quite a few species, albeit in minor abundances, belong to the order *Ficalhoo-Podocarpetalia*; this and the presence of exponents of further classes sustain the question of whether or not a strict classification according to the Braun-Blanquet system is adequate. Fischer & Killmann (2008, p.13) placed the border between the medium and the upper level of the montane forest around 2600 m +/- 100 (-200) m a. s. l., which would put the sites right within a possible ecotone between those two altitudinal forest types, thus explaining the high intermixture. An alternative would be the replacement of *Podocarpus* dominated primary forests by the secondary communities encountered, either due to natural causes, mostly fire, or due to anthropogenic impact. Given the circumstances, a preliminary denomination would be the *Macaranga* dominated secondary community which could be placed within the standard tree secondary forests of Fischer & Hinkel (1994).

At this point, some remarks on plot 75_{NM} seem to be in order. The vigilant reader will have noticed the rather low species count and the fact that only one tree layer is present within the plot. When probing the site in November 2015, it was used as pasture for livestock. The herbal layer was of a secondary character, the shrub layer barely developed and the third and second tree layer were missing entirely.

Rather reluctantly, plot 70_{NM} will also be included in the cluster at hand. Originally, the FCM-NC algorithm found the site belonging to another cluster which comprised two further plots (32_{NB} and 73_{NM}, see page 160). On the other hand, UPGMA joined site 70_{NM} a little closer to the sites discussed in this paragraph. Due to species composition and the UPGMA results, plot 70_{NM} will be combined with the sites investigated in this paragraph. However, the average dissimilarity of about 66 % does weaken the cluster integrity. The site at Musebeya sets itself apart through a heightened abundance of *Myrsine melanophloeos*. The pertinent literature does not help in classification of the vegetation of the site. No vegetation type has been found in which *R. melanophloeos* dominates or the name of which includes the species. HABIYAREMYE (1997) placed the species within the *Polyscietalia fulvae* and refers to LEBRUN & GILBERT who, in their 1954 work, never mentioned the occurrence of the species in said order. Instead, they placed the species into the order Oleo-Jasminetalia and here, within the alliance Agaurio-Myricion. According to SCHMITZ (1988) (see LEWALLE, 1972) all other classifications also put the species into sclerophyllos vegetation, an assignment which, with the exception of a few species including *Myrsine* itself, does not fit the vegetation of the plots belonging to the cluster examined here. At least *Myrsine* seems to occur in secondary vegetation, according to HABIYAREMYE (1997) also within the Macarango-Psychotrietum. As explained above, this is a vegetation type close to the current subject. Another plot which will be subsumed under the vegetation type just described is plot 61_{NR}. Though *Macaranga* only occurs with a decreased abundance and most of the canopy is dominated by climbers, the vegetation character changes only slightly and does not hinder clustering. The average dissimilarity within the cluster is increased only by ca. 2%, and the secondary probability given by FCM-NC amounts to 0.29 for cluster M28. The UPGMA results differ slightly, suggesting either to treat 61_{NR} as a singleton or to join it with plot 37_{NGa}. Although the dissimilarity of about 68% to site 37_{NGa} does not completely prevent a merging, mere species composition does. The joint at the 52% information level of the dendrogram obtained by UPGMA would suggest an equal option to join the plot with the sites constituting cluster M20 (§ 3.2.16). Further scrutinisation does prevent such an endeavour on the basis of an even more dissimilar vegetation composition and an unduly abated cluster integrity in terms of Bray-Curtis values.

Up until now, the sites located in Gishwati Forest have been neglected. Not only does vegetation composition differ to a distinguishable extent, but the morphology is another feature rendering a fusion dowdy and imprecise. Thus, the plots situated in Gishwati Forest will be separated and scrutinised in the next paraph. This decision is also founded on the UPGMA dendrogram where plots 83Gw and 91Gw are joined with the other plots directly at the 76% information level.

Table 3.61: *Macaranga kilimandscharica* dominated secondary community

Sample Site / Species	$^{33}\mathrm{NGa}$	$^{43}\mathrm{NK}$	$^{44}\mathrm{NK}$	$^{61}\mathrm{NR}$	$^{70}\mathrm{NM}$	$^{75}\mathrm{NM}$
Exposition	S	NW	SW	N	SSE	SSW
Inclination [°]	22	26	40	37.5	33	27.5
Position / Relief	HU	OH	HM	HM	HM	HM
Precipitation / a [mm]	1675	1647	1631	1655	1261	1261
Elevation a.s.l. [m]	2381	2316	2289	2315	2522	2515
T S_{60} [°C]	13.5	14.90	15.10	14.50	14.50	15.00
pH	3.17	3.07	2.91	3.14	2.63	2.98
Soil texture	Sl	Sl	Sl	Ts	Ts	Ts
t Height [m]	27.34	24.3	31.3	22.25	27.4	28.01
t1 Height [m]	8	15.2	12.12	7	6	n/a
t2 Height [m]	n/a	n/a	6	4	4	n/a
t3 Height [m]	n/a	n/a	n/a	n/a	n/a	n/a
Shrub Height [m]	3	3.1	2.5	2.3	2.5	2
Herb Height [m]	1.3	1	1.5	0.6	0.4	0.5
Moss Height [m]	n/a	n/a	n/a	n/a	n/a	n/a
Juvenil Height [m]	0.15	n/a	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	n	1	0	1	1	1
Vegetation Cover [Londo]	10	10	10	10	10	10
t Cover [%]	23.00	64.00	7.92	87.75	138.75	63.25
t1 Cover [%]	22.33	13.50	15.00	16.75	1.25	0
t2 Cover [%]	0	0.00	31.67	6.50	4.92	0
t3 Cover [%]	0	0	0	0	0	0
Shrub Cover [%]	15.67	18.17	4.00	4.17	54.42	0.25
Herb Cover [%]	21.33	23.58	59.00	3.67	4.50	68.58
Moss Cover [%]	n/a	n/a	n/a	n/a	n/a	n/a
Juvenil Cover [Londo]	5-	a1	n	a2	p1	p1
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	p1	n/a	n/a
Macaranga kilimandscharica	5-	5-	5-	3	6	6
Begonia meyeri-johannis	1.2	0.7	p1	a1	p1	p2
Blotiella glabra	p1	p1	3		p2	p1
Urera hypselodendron	r1	p1	r1	p1		p1
Allophylus chaunostachys	p2	r1	r1		p1	
Sericostachys scandens	p1	p1	1.2	r1	5+	
Carapa grandiflora	r1	p1		1.2		
Galiniera saxifraga	p1	p1			r1	
Pteridium aquilinum	p2		0.7		p1	p2
Polyscias fulva		3		r1		
Chassalia subochreata	r1				p2	
Myrianthus holstii	p2			r2		
Impatiens gesneroidea	p2	a1			p1	
Asplenium cf. friesiorum	p1				p1	p1
Neoboutonia macrocalyx		r1				
Pilea rivularis		p1				
Clerodendrum johnstonii		p1				
Mikania cordata	0.7					
Phyllanthus nummularifolius	p1					
Xymalos monospora	r1					
Psychotria mahonii						r1
Coleus autranii			1.2			7
Triumfetta cordifolia		p1	p1			
Ipomoea involucrata		p1	p1			
Rubus cf. pinnatus		p1	p1			

Table 3.61: *Macaranga kilimandscharica* dominated secondary community (continued)

Sample Site / Species	^{33}NGa	^{43}NK	^{44}NK	^{61}NR	^{70}NM	^{75}NM
Mimulopsis arborescens		p1	p1			
Coccinia sp.		p2	p1			
Symphonia globulifera				p1		
Asplenium sandersonii				p1		
Salacia erecta					r1	
Clutia abyssinica		p1			r1	
Gynura scandens			p1	p1		
Mikaniopsis usambarensis	0.7				p1	
Hypolepis sparsisora		1.2				
Mikania chenopodiifolia		1.2				
Syzygium parvifolium		p1				
Coccinia mildbraedii		p1				
Pilea bambuseti		p1				
Coleus sylvestris		p1				
Dichanthelium hillebrandianum		a1				
Diplazium sp. VI		p1				
Cyperus sp. III		r1				
Asplenium sp. XXII		p1				
Magnistipula butayei			0.7			
Stephania abyssinica			r1			
Mimulopsis excellens			p1			
Rubus cf. apetalus			p1			
Pilea cf. bambuseti			r1			
Adenia sp.			r1			
Rubus sp. VII			p1			
Asplenium friesiorum	r1					
cf. Cyanotis vaga	r1					
Diplazium sp. III	p1					
Keetia sp. III	p1					
Mikania sp. I	p1					
Dryopteris sp. XV	r1					
Asplenium sp. XXII	r1					
Dryopteris sp. XII	p1					
Clematis simensis						r1
Mikania chenopodiifolia						p1
Rubus cf. pinnatus						p1
Asplenium sp. XXXVIII						p1
cf. Coccinia sp. II						r1
Adenochloa claytonii						p1
cf. Hippocratea sp.				0.7		
Astropanax goetzenii				p1		
Alchornea hirtella				p4		
Asplenium sp. VI				p1		
Ilex mitis				r4		
Elaphoglossum sp.				p1		
Impatiens sp.				r1		
Dalbergia lactea				p1		
Vittaria sp.				r1		
Astropanax abyssinicus				p1		
cf. Peperomia sp. IV				p1		
Asplenium cf. linckii				p1		
Acalypha volkensii				p1		

Table 3.61: *Macaranga kilimandscharica* dominated secondary community (continued)

Sample Site / Species	33$_{NGa}$	43$_{NK}$	44$_{NK}$	61$_{NR}$	70$_{NM}$	75$_{NM}$
Asplenium pellucidum ssp. pseudohorridum				p1		
Canarina eminii				p1		
Dryopteris sp. IX				a2		
Myrsine melanophloeos					8	
Impatiens purpureo-violacea					a2	
Keetia gueinzii					r1	
Pleopeltis macrocarpa					m2	
Asplenium dregeanum					r1	
Asplenium cf. theciferum					r1	
Asplenium sp. XXXV					p1	
Blotiella cf. glabra					a2	
Psychotria cf. peduncularis					p1	
Dryopteris sp. X					p1	
Rytigynia sp. I					r1	
Mikaniopsis sp. II					p1	
Ficus ottonifolia					p1	
Canthium sp.					r1	
Asplenium cf. mannii					m1	

Further species in the samples: **33**$_{NGa}$: Gen. indet. spec. indet. LXXXIX r1; **43**$_{NK}$: Gen. indet. spec. indet. CI p1; Rubiaceae sp. VI p1; **44**$_{NK}$: Gen. indet. spec. indet. CI r1: Gen. indet. spec. indet. CIII p1; Gen. indet. spec. indet. CV r1; Polypodiales sp. VIII p1; Gen. indet. spec. indet. CIV r1; Gen. indet. spec. indet. CVI r1; Chrysobalanaceae sp. r1; Gen. indet. spec. indet. CII r1; **61**$_{NR}$: Gen. indet. spec. indet. CLXXV 5- ; Rubiaceae sp. IX r1; Gen. indet. spec. indet. CLXXVII r1; Gen. indet. spec. indet. L r1; Apocynaceae sp. III r1; Cucurbitaceae sp. XVI r1; **70**$_{NM}$: Asplenium sp. IV p1; Dryopteris sp. XII r1; Dryopteris sp. IX p1; Gen. indet. spec. indet. XXXV r1; Rubiaceae sp. V p1; Gen. indet. spec. indet. XXXVIII r1; **75**$_{NM}$: Cucurbitaceae sp. IX r1; Gen. indet. spec. indet. XVII p1; Gen. indet. spec. indet. LXII p1

3.2.29 *Macaranga kilimandscharica* Secondary Forest

Fuzzy k-means cluster number: M28.2
UPGMA, local cut information level: 97 %
Plots: 83$_{Gw}$, 91$_{Gw}$ Location: Gishwati forest

Dissimilarity (Bray-Curtis): 0.42 Distance [km]: 2.07

Gishwati forest only extends over 14.84 km^2 (Nyiratuza, 2014). The core forest, which has not yet been overgrown by *Acacia sp.* and could be described as a natural stand, i.e., has not been reforested, is even smaller (8.86 km^2, Nyiratuza, 2014) but still holds considerable diversity.

The previously described vegetation community offers only 11 species in common with the plots in Gishwati Forest. This low congruence alone might not be sufficient to refuse a combination, but the morphology of the stand adds to the reservations against a fusion.

Within the tree layer, *Macaranga kilimandscharica* prevails in both plots bringing about the main similarity. *Polyscias fulva* also occurs in both sites with only a minor abundance but still provides testimony of the secondary character of the forest. *Maesa lanceolata* is present in both sites with considerable abundance. According to Fischer & Hinkel (1994), the community could be collated to the secondary low-stemmed tree forests (Niedrigstämmige Sekundärwälder). In particular, the *Macaranga kilimandscharica* secondary forest seems to be the appropriate unit. *Urera hypselodendron*, which can also be found in both plots, is quite common and euryoecious and might not be well suited to characterise a community. Nevertheless, it was also found by Fischer & Hinkel (ibid.) within the community at hand. *Myrianthus holstii*, *Bersama abyssinica*, *Neoboutonia macroclayx* and *Dombeya torrida* are underlining the affiliation. For a complete species list compare Table 28 and cf. Hinkel & Fischer (1994) Tab. 6 p. 55 ff.

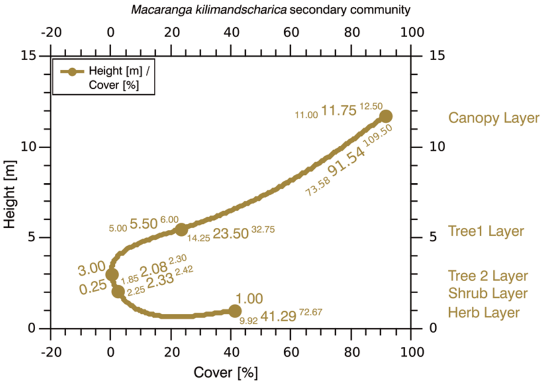

Figure 3.37: Cover-Height relation of the community recovered in Gishwati Forest; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Lebrun & Gilbert (1954) described the order *Polyscietalia fulvae* to which the two clustered plots could be assigned. Despite the species mentioned above, *Hagenia abyssinica* and *Xymalos monospora* further substantiate the secondary character. Habiyaremye (1997) subsumes the vegetation at hand under recrûs et forêts secondaire and further under La forêt à *Macaranga neomildbraediana* et *Psychotria mahonii* –Macarango-Psychotrietum mahonii.

Both methods, UPGMA and FCM-NC, give similar results, placing the two plots into the same cluster. With a local cut of the UPGMA tree at about the 97% information level, the two sample plots seem to have a quite high resemblance; however, a 42% dissimilarity doos not yield for an irrefutable result.

The sites are situated at the medium level of the montane rain forest and face south. Soil depth is right in the medium range of the measured drillable soil depths; the mean annual temperature varies around 15.00°C; while the sandy soils have a pH value of 3.44 and 3.93, respectively. In both plots, three tree layers are present reaching a maximum head of 12.50 m. In both cases, the shrub cover is barely developed, while the density of the herb layers strongly differs with ∼10% in plot 83_{Gw} and ∼73% in plot 91_{Gw}.

Table 3.62: *Macaranga kilimandscharica* secondary community

Sample Site / Species	83_{Gw}	91_{Gw}
Exposition	S	S
Inclination [°]	42	30
Position / Relief	HO	HU
Precipitation / a [mm]	1357	1365
Elevation a.s.l. [m]	2343	2212
T S_{60} [°C]	14.50	15.30
pH	3.44	3.93
Soil texture	Sl	Su
t Height [m]	11.00	12.50
t1 Height [m]	6.00	5.00
t2 Height [m]	3.50	3.00
t3 Height [m]	n/a	n/a
Shrub Height [m]	2.3	1.85
Herb Height [m]	1	1
Moss Height [m]	0.02	n/a
Juvenil Height [m]	n/a	n/a
Epiphyts [m/6m]	0	1
Vegetation Cover [Londo]	10	10
t Cover [%]	73.58	109.50
t1 Cover [%]	32.75	14.25
t2 Cover [%]	0	0.25
t3 Cover [%]	0	0
Shrub Cover [%]	2.25	2.42
Herb Cover [%]	9.92	72.67
Moss Cover [%]	1.33	n/a
Juvenil Cover [Londo]	p1	p1
Juvenil Shrub Cover [Londo]	p1	p1
Urera hypselodendron	0.7	p1
Macaranga kilimandscharica	5+	6
Polyscias fulva	r2	r1
Maesa lanceolata	3	4
Rubus cf. pinnatus	p1	r1
Ipomoea sp.	r1	p1
Commelina sp.	p1	p1
Neoboutonia macrocalyx	0.7	
Xymalos monospora	p2	
Hagenia abyssinica	1.2	
Thalictrum rhynchocarpum	p1	
Senecio maranguensis	r1	
Vernonia sp.	r1	
Rubus cf. apetalus	p1	
Ardisiandra wettsteinii	r1	
Pteris cf. pteridioides	p1	
Dombeya torrida	r1	
Liparis bowkeri	p1	
Adenochloa cf. claytonii	m1	
Achyranthes aspera	r1	
Gymnanthemum auriculiferum	r1	
Dryopteris sp. VII	p1	
Pavonia sp. I	m2	
Pteris catoptera	p1	
Ipomoea sp. I	p1	
Cyphostemma bambuseti	p1	

Table 3.62: *Macaranga kilimandscharica* secondary community (cont.)

Sample Site / Species	83_{Gw}	91_{Gw}
Cyperus sp. V	r1	
Lactuca sp.	p1	
Stephania sp.	r1	
Mikania sp. VI	p1	
Gynura sp.	p1	
Asplenium sp. XXXIV	r1	
Mimulopsis solmsii		p2
Bersama abyssinica		p2
Myrianthus holstii		0.7
Cyphostemma sp.		r1
Asplenium sp. VI		r1
Asplenium cf. mildbraedii		r1
Dichanthelium cf. hillebrandianum		p1
Pilea bambuseti		3
Pteris cf. preussii		r1
Acalypha ornata		p1
Asplenium cf. mannii		m1
Drymaria sp.		p1
Dryopteris sp. XIII		r1
cf. Oxyanthus sp.		r1
Brillantaisia cicatricosa		p2
Pilea rivularis		p2
Acalypha sp. I		p1
Phyllanthus sp.		p1
cf. Gynura sp.		p1
Cyperus sp. VIII		p1
Asplenium sp. XI		p1
Asplenium sp. XIX		p1
Ficus sp. I		r1
cf. Marsdenia sp.		1.2

Further species in the samples: **83_{Gw}**: Polypodiales sp. VIII p1; Poaceae sp. X p1; Bryopsida sp. IV m2; Cyperaceae sp. I p1; Gen. indet. spec. indet. CXCII r1; Polypodiales sp. I r1; Poaceae sp. XI r1; Polypodiales sp. XIII r1; **91_{Gw}**: Cucurbitaceae sp. XVIII p2; Cucurbitaceae sp. XXI r1; Polypodiales sp. VII p1; Gen. indet. spec. indet. XLVIII p2; Cucurbitaceae sp. XIII r1; Woodsiaceae sp. II r1; cf. Woodsiaceae sp. VI r1; Gen. indet. spec. indet. LVI p1; Gen. indet. spec. indet. XXVI 3; Gen. indet. spec. indet. XV p2; Rubiaceae sp. XVIII r1; Cucurbitaceae sp. XIV p1; Gen. indet. spec. indet. XIV p1; Woodsiaceae sp. III p1; Gen. indet. spec. indet. XXXII p1

3.2.30 *Dombeya rotundifolia-Polyscias-Acanthaceae* sp. XII Community

Fuzzy k-means cluster number: M33

UPGMA, local cut information level: 10% (89_{Gw}); 37% (68_{NBw})

Plots: 87_{Gw} Locations: Gishwati Forest

M33	68_{NBw}	87_{Gw}	89_{Bw}
68_{NBw}	0	0.7	0.99
87_{Gw}		0	0.55
89_{Bw}			0

Table 3.63: Bray-Curtis dissimilarities between the samples discussed.

M33	68_{NBw}	87_{Gw}	89_{Gw}
68_{NBw}	0	88.67	88.08
87_{Gw}		0	1.47
89_{Gw}			0

Table 3.64: Geographic distances between the samples discused in km.

Despite the moderate dissimilarity to plot 89_{Gw}, plot 87_{Gw} should not be merged with cluster M1+M24. The similarity to plot 89_{Gw} is brought about by a yet unidentified *Acanthaceae sp*. XII within the herb layer, and the other commonalities (four more species) are only present in minor abundances. Since *Dombeya* cf. *rotundifolia* only occurs once within the survey it has been removed prior to the analyses and, therefore, the clustering algorithms were working accordingly. It follows that the total dissimilarity between the stands is even higher than the BRAY-CURTIS values given above (annex 3). Taking the dominance of said species into account, an allocation to a found vegetation unit is not advisable. The tree layer and the second tree layer differ almost completely. It is here where an argument about stratification and sampling design could be exerted. If one looks at the second tree layer of plot 87_{Gw} and the first tree layer of plot 89_{Gw}, differences become less apparent. Since no further data is available, the assumption of *Polyscias fulva* also being present in the vicinity of plot 89_{Gw} cannot be made. Thus, as long as *D.* cf. *rotundifolia* does not turn out to also be *D. torrida*, a discussion about clustering the plots at hand is muted.

In their treatise of the Gishwati Forest, FISCHER & HINKEL (1994) did not mention *D. rotundifolia*. Still, the classification as a secondary forest seems appropriate in view of species composition. An assignment to the Polyscion fulvae poses no dilemma. The subsequent classification into the existing system is not possible. In none of the pertinent literature is *D. rotundifolia* listed in an adequate community. As a result, a temporary solution will be created. A *Dombeya rotundifolia-Polyscias-Acanthaceae* sp. XII community will be the auxiliary construct to be used in the considerations that follow. The community can be found at the medium level of the montane rain forest on sandy and rather shallow soil. The pH value amounts to 3.96. The mean annual temperature of the NNW facing plot is about 15°C. Three tree layers are apparent, the highest of which reaches 30 m and covers a barely existent shrub and a dense herb layer as well.

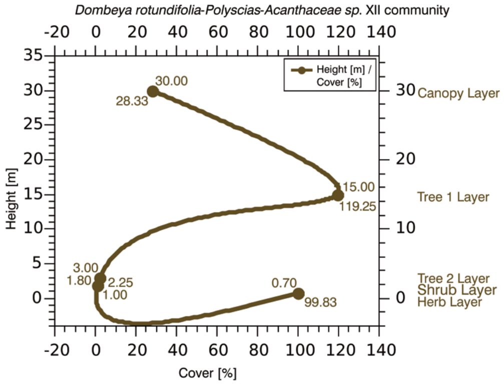

Figure 3.38: Cover-Height relation of the community recovered in Gishwati Forest; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Table 3.65: *Dombeya rotundifolia-Polyscias-Acanthaceae sp.* XII community

Sample Site / Species	^{66}NBw	^{67}NBw	^{68}NBw	^{87}Gw	^{89}Gw
Exposition	SW	NNW	SW	NNW	NNW
Inclination [°]	20	22	51	30	38
Position / Relief	HM	HO	HM	HM	HM
Precipitation / a [mm]	1865	1836	1836	1363	1376
Elevation a.s.l. [m]	2012	1893	1811	2222	2126
T S_{60} [°C]	16.30	17.70	17.00	14.90	15.00
pH	4.02	3.39	3.38	3.96	4.88
Soil texture	Ts	Sl	Sl	Sl	Us
t Height [m]	16.00	19.00	12.50	30.00	11.00
t1 Height [m]	11.00	7.00	9.00	15.00	4.50
t2 Height [m]	5.00	4.00	4.00	3.00	n/a
t3 Height [m]	n/a	n/a	n/a	n/a	n/a
Shrub Height [m]	2.50	2.00	2.50	1.80	2.50
Herb Height [m]	1.10	0.60	0.90	0.70	1.10
Moss Height [m]	n/a	n/a	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1	1	1
Vegetation Cover [Londo]	10	10	10	10	10
t Cover [%]	103.00	54.83	48.58	28.33	101.17
t1 Cover [%]	9.67	45.58	38.25	119.25	3.67
t2 Cover [%]	13.83	2.42	3.17	2.25	0
t3 Cover [%]	0	0	0	0	0
Shrub Cover [%]	13.25	0.25	21.17	1.00	4.75
Herb Cover [%]	63.08	71.92	37.17	99.83	85.50
Moss Cover [%]	n/a	n/a	n/a	n/a	n/a
Juvenil Cover [Londo]	n/a	p1	a1	r1	p1
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	n/a	p1
Maesa lanceolata	8	7	4	2	r1
Macaranga kilimandscharica	p1	0.7	0.7		
Polyscias fulva		r1	4	3	
Rubus cf. apetalus	r1	p1	p1		
Gouania longispicata	p4	p1	p1		
Shirakiopsis elliptica	r1	p1	p1		
Pteris sp. VI	p1	p1	p1		
Croton macrostachyus	3	r1	p4		
Sericostachys scandens	6			0.7	
Pteris cf. pteridioides	r1			r1	
Alchornea hirtella	r1	p1			
Asplenium sandersonii	p1	r1			
Mimulopsis arborescens	p1	a1			
Psychotria peduncularis	p1	r1			
Bridelia brideliifolia	r1	r1			
Allophylus chaunostachys		r1		p1	
Isoglossa sp.	p1		r1		
Arthropteris cf. monocarpa		4	2		
Urera trinervis		p4	0.7		
Drymaria cordata		p1	p1		
Asplenium cf. friesiorum		a1	r1		
Grona ramosissima		p4	p1		
Urera hypselodendron	p1				1.2
Solanum chrysotrichum		p1			r1
Isachne mauritiana			2		p1

Table 3.65: *Dombeya rotundifolia-Polyscias-Acanthaceae sp.* XII community (continued)

Sample Site / Species	66_{NBw}	67_{NBw}	68_{NBw}	87_{Gw}	89_{Gw}
Thalictrum rhynchocarpum				r1	p1
Acalypha ornata				p1	p1
Vernonia sp. IV				p1	p2
Begonia meyeri-johannis	p4				
Triumfetta cordifolia	p1				
Neoboutonia macrocalyx	p1				
Mimulopsis excellens	p1				
Laportea alatipes	p1				
Alangium chinense	p1				
Pleopeltis macrocarpa	r1				
Asplenium aff. elliottii	p1				
Clerodendrum buchananii	p2				
Pteris sp. V	p1				
cf. Cucumis sp. I	p1				
Asplenium cf. tenuicaudatum	p1				
Piper cf. capense	p1				
Cucumis sp. I	r1				
Bersama abyssinica var. engleriana	p1				
Poecilostachys oplismenoides		3			
Hymenodictyon floribundum		1.2			
Harungana montana		0.7			
Apodytes dimidiata		r1			
Asplenium sp. IV		p1			
Asplenium cf. mildbraedii		r1			
Landolphia buchananii		p1			
cf. Microlepia speluncae		r1			
cf. Stellaria sp.		p1			
Mikania sp. IV		p1			
Zehneria sp. II		r1			
Orbivestus karanguensis		r1			
Peponium vogelii		r1			
Monosis conferta		p4			
Leptactina platyphylla			1.2		
Cyperus sp. III			p1		
Ritchiea albersii			r1		
Zanthoxylum gilletii			r1		
Canarina eminii			p1		
Rubus cf. pinnatus			r1		
Bonny repens			r1		
cf. Lobelia giberroa			p1		
Tristemma sp.			r1		
Ficus sp. VII			r1		
Anthocleista grandiflora			r1		
Ficus natalensis			r1		
Dombeya cf. rotundifolia				10	
Tacazzea apiculata				p1	
Piper capense				p1	
Rubus cf. pinnatus				r1	
Psychotria cf. mahonii				r1	
Loxogramme abyssinica				r1	
Cyperus sp. VI				p1	
Pteris cf. microlepis				r1	

Table 3.65: *Dombeya rotundifolia-Polyscias-Acanthaceae sp.* XII community (continued)

Sample Site / Species	66_{NBw}	67_{NBw}	68_{NBw}	87_{Gw}	89_{Gw}
Hylodesmum repandum				p1	
Brillantaisia cicatricosa				p1	
Tectaria sp.				r1	
Momordica sp.				p1	
cf. Cucumis sp.				p1	
cf. Pilea sp.				r1	
Dombeya torrida					9
Syzygium parvifolium					p2
Clerodendrum johnstonii					p1
Pilea sp. II					p1
Dalbergia lactea					p1
Ipomoea sp.					p1
Pilea rivularis					p1
Girardinia bullosa					p1
Croton megalocarpus					r1
cf. Monanthotaxis orophila					r1
Pilea cf. rivularis var. rivularis					p1

Further species in the samples: **66_{NBw}**: Amaranthaceae sp. 2; Gen. indet. spec. indet. XVIII p1; Vernonieae sp. p1; Gen. indet. spec. indet. XIX r1; **67_{NBw}**: Gen. indet. spec. indet. XXIV r1; Apocynaceae sp. II p1; Gen. indet. spec. indet. XXII p1; Gen. indet. spec. indet. XXIII r1; Gen. indet. spec. indet. XX r1; Gen. indet. spec. indet. XXV p4; **68_{NBw}**: Gen. indet. spec. indet. XXIV r1; Gen. indet. spec. indet. XXXI r1; Gen. indet. spec. indet. XXX r1; **87_{Gw}**: Acanthaceae sp. XII 10 ; Acanthaceae sp. XI p4; Gen. indet. spec. indet. CXXIV p1; Cucurbitaceae sp. XXII p1; Gen. indet. spec. indet. XIII r1; Gen. indet. spec. indet. CXX p1; Gen. indet. spec. indet. XCVII r1; Rubiaceae sp. XVI r1; **89_{Gw}**: Acanthaceae sp. XII 8; Cucurbitaceae sp. XIX p1; Gen. indet. spec. indet. CLXXIX p1; Acanthaceae sp. VIII p1; Woodsiaceae sp. V p1; Fabaceae sp. II p1; Gen. indet. spec. indet. LII p2

3.2.31 *Syzygium parvifolium-Symphonia globulifera-Lasianthus kilimandscharicus* Community

Fuzzy k-means cluster number: M27
UPGMA, local cut information level: 80 %
Plots: 76_{NGk}, 77_{NGk} Location: Gisakura

Dissimilarity [Bray-Curtis]: 0.55 Distance [km]: 4,75

The similarity of the plots 4.75 km apart which have been grouped by UPGMA and FCM-NC only amounts to 45%. The UPGMA cluster is derived from a local cut at the 80% information level. *Syzygium parvifolium* covers about half of the plot, respectively. The tree stratum holds *Harungana montana*, *Carapa grandiflora*, *Senegalia montigena* and an unidentified epiphyte in site 76_{NGk}. In site 77_{NGk}, *Symphonia globulifera* co-dominates. In the same plot, *S. parvifolium* also occurs in the other two tree layers. *Lasianthus kilimandscharicus* is growing in the shrub and the third tree layer of both plots with considerable cover. Moreover, *Chassalia subochreata* is also present in both plots, and *Allophylus chaunostachys* can be found in the third tree layer in both plots in minor abundances. Within the herb layer, and partly epiphytic in the shrub layer, *Arthropteris* cf. *monocarpa*, *Hymenophyllum triangulare*, *Cincinnobotrys speciosa*, *Rhodobryum keniae*, *Asplenium dregeanum* and *Haplopteris guineensis* were found in both plots in minor abundances.

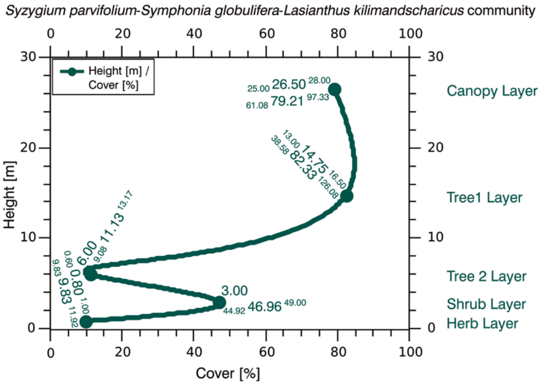

Figure 3.39: Cover-Height relation of the community recovered near Gisakura; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Existing classifications do not permit an assignment of the vegetation of the two plots to any sociological unit. It is not even possible to determine whether they are primary or secondary forests. The only permissible classification is into the class *Strombosio-Parinarietea* Lebrun & Gilbert 1954. A preliminary suggestion would be a *Syzygium parvifolium-Symphonia globulifera-Lasianthus kilimandscharicus* community. Both sites, which are positioned at the medium and upper level of the montane rain forest are facing SE-ward. The drillable soil depth reaches 1.88 and 0.24 metres, respectively. The measured temperature in 0.60 m soil depth amounts to 17.00°C, while the pH varies between 3.11 and 3.28, respectively. The three tree layers present in both sites reach a maximum height of 28 m and shade a well-developed shrub layer and a sparse herb layer in both cases.

Table 3.66: *Syzygium parvifolium-Symphonia globulifera-Lasianthus kilimandscharicus* community

Sample Site / Species	^{76}NGk	^{77}NGk
Exposition	SE	SE
Inclination [°]	46	40
Position / Relief	KH	KM
Precipitation / a [mm]	2530	2866
Elevation a.s.l. [m]	1849	1997
T S_{60} [°C]	17.00	n/a
pH	3.11	3.28
Soil texture	Sl	Sl
t Height [m]	28.00	25.00
t1 Height [m]	16.50	13.00
t2 Height [m]	6	6
t3 Height [m]	n/a	n/a
Shrub Height [m]	3.00	3.00
Herb Height [m]	1.00	0.60
Moss Height [m]	n/a	n/a
Juvenil Height [m]	n/a	n/a
Epiphyts [m/6m]	1	1
Vegetation Cover [Londo]	10	10
t Cover [%]	61.00	97.33
t1 Cover [%]	12.08	38.58
t2 Cover [%]	13.17	9.08
t3 Cover [%]	0	0
Shrub Cover [%]	44.92	49.50
Herb Cover [%]	11.92	9.83
Moss Cover [%]	n/a	n/a
Juvenil Cover [Londo]	0.7	p2
Juvenil Shrub Cover [Londo]	n/a	n/a
Syzygium parvifolium	4	7
Symphonia globulifera	3	4
Lasianthus kilimandscharicus	2	5-
Carapa grandiflora	2	p2
Chassalia subochreata	3	r2
Arthropteris cf. monocarpa	p2	0.7
Apodytes dimidiata	r1	r1
Asplenium dregeanum	m2	p1
Allophylus chaunostachys	r1	p1
Hymenophyllum triangulare	p1	m1
Cincinnobotrys speciosa	p1	p2
Rhodobryum keniae	m1	p1
Haplopteris guineensis	p1	p1
cf. Syzygium sp.	3	
Cleistanthus polystachyus	3	
Harungana montana	2	
Celtis gomphophylla	p2	
Microcos mildbraedii	0.7	
Culcasia falcifolia	r1	
Coffea eugenioides	r1	
Gambeya gorungosana	p2	
Senegalia montigena	r1	
Loxogramme lanceolata	r1	
Dracaena laxissima	p1	
Myrianthus holstii	p1	

Table 3.66: *Syzygium parvifolium-Symphonia globulifera-Lasianthus kilimandscharicus* community (cont.)

Sample Site / Species	76_{NGk}	77_{NGk}
Cassipourea ndando	p1	
Xymalos monospora	r1	
Ocotea usambarensis	r2	
Asplenium sandersonii	m1	
Macaranga kilimandscharica	r1	
Alchornea hirtella	p2	
Asplenium cf. gemmiferum	p1	
Asplenium sp. IV	r1	
Chlorophytum comosum	r1	
Psychotria cf. parvistipulata	p1	
Asplenium sp. XL	p1	
Commelina sp. I	p1	
Agelaea pentagyna	p1	
Pentadesma reyndersii	p4	
Rytigynia sp. VII	r1	
Podocarpus latifolius		2
Maytenus acuminata		0.7
Parinari excellsa		p1
Asplenium tenuicaudatum		p1
Vittaria reekmansii		p1
Stephania abyssinica		r1
Oxyanthus speciosus		p1
Myrsine melanophloeos		p1
Nuxia congesta		r1
Monanthotaxis orophila		r1
Pilea johnstonii		p1
Dryopteris sp. IX		p1
Virectaria major		p1
Rytigynia sp. II		r1
Smilax anceps		p1
Liparis bowkeri		p1
Hymenodictyon floribundum		p1
Anthocleista grandiflora		r1
cf. Isachne mauritiana		p1
Asplenium sp. XXXVIII		r1
Sabicea bequaertii		p1
cf. Pilea sp. I		a1
Astropanax myrianthus		p2
Asplenium sp. XLII		p1
cf. Alafia sp.		r1
cf. Lasianthus sp.		p1
cf. Uvaria sp.		r2
cf. Rytigynia sp.		r1
Clerodendrum sp. I		p1
Dichaetanthera corymbosa		p2
Englerophytum rwandense		r1
Polygala engleri		p1
Bulbophyllum cf. cochleatum		r1

Further species in the samples: 76_{NGk}: Bryopsida sp. m1; Gen. indet. spec. indet. LXVIII 2; Gen. indet. spec. indet. XXI p4 ; 77_{NGk}: Gen. indet. spec. indet. XLVI r1; Rubiaceae sp. XI r1; Caryophyllaceae sp. III r1; Apocynaceae sp. VI p1; Apocynaceae sp. VII r1; Bryopsida sp. II m1; Bryopsida sp. I m1; Rubiaceae sp. III r1

3.2.32 *Cleistanthus polystachyus-Carapa grandiflora-Senegalia montigena* Community

Fuzzy k-means cluster number: M5

UPGMA, local cut information level: 47 %

Plots: 52_{NGs} Locations: Nyungwe, Gasumo

Dissimilarity (Bray-Curtis): 0.68 (to 76_{NGk}) Distance [km]: 9.79 (to 76_{NGk})

The SE-facing site is situated in the lower level of the montane rain forest. The drillable soil depth reaches 0.99 m, and the clay soil has a pH value of 2.95. The mean annual temperature reaches 17.70°C. Underneath the 20 m high canopy, two more tree strata can be found as well as an almost non-existent shrub and herb layer.

The difficulties arising during the evaluation of the vegetation of this plot follow as yet another example from the axiomatic utilisation of a classification system designed to describe European, i.e., rather species poor vegetation on a tropical plant cover.

Even though the relatively high dissimilarity based on the Bray-Curtis index and the late joint in the UPGMA tree seem inhibiting, similarities in species composition between plot 76_{NGk} and 52_{NGs} are tempting enough to consider a grouping of the plots under the banner of the vegetation community established in the paragraph above. Still, the absence of *Syzygium parvifolium* and *Lasianthus kilimandscharicus* is prohibitive of further combination without additional data. This issue and those discussed on the matter of species patterns and plot size thwart the previous statement. Consequently, a combination of clusters M27 and M5 is not unlikely with an ameliorated data basis.

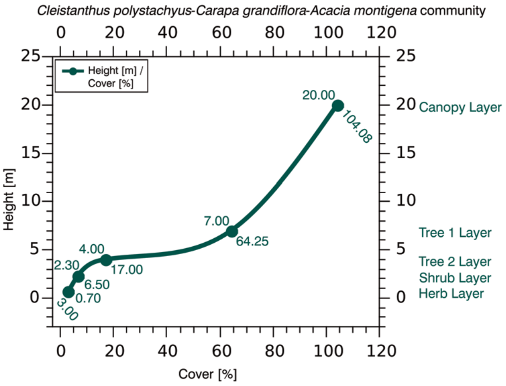

Figure 3.40: Cover-Height relation of the community recovered near Gasumo; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

As abundance patterns of *C. polystachyus* could not be researched to an adequate extent, a possible characterisation of a stand by this species cannot entirely be ruled out. According to the African Plant Database, *C. polystachyus* can be common locally (Conservatoire et Jardin botaniques & South African National Biodiversity Institute, 2012). Bloesch et al. (2009) have even stated: "Appartient à la strate dominante ou codominante en forêt de montagne, souvent en association avec *Newtonia buchananii* et *Parinari excelsa* [...]." The same authors placed the species into the primary montane forests (ibid.). Habiyaremye (1997) placed the species into the class Strombosio-Parinarietea,[1] a classification which will be followed here. The vegetation of the stand found near Gisovu is close to what Fischer (1996) described as *Albizia gummifera-Carapa grandiflora-Parinari excelsa*, the primary forests of the lower forest level. Though the conspicuous presence of *S. montigena* draws a bit off the primary character, the assumption will be maintained albeit a bit degraded. Since no further community under dominance of *C. polystachyus* could be found in the existing literature, a preliminary name for this community could be *Cleistanthus polystachyus-Carapa grandiflora-Senegalia montigena*.

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[1] Yet again, the classification could not be traced back in the original source.

Table 3.67: *Cleistanthus polystachyus-Carapa grandiflora-Senegalia montigena* community

Sample Site / Species	^{69}NBw	^{52}NGs	^{76}NGk
Exposition	WSW	SO	SO
Inclination [°]	30	30	46
Position / Relief	HU	HM	KH
Precipitation / a [mm]	1865	2201	2530
Elevation a.s.l. [m]	1915	1965	1849
T S_{60} [°C]	16.00	17.70	17.00
pH	3.17	2.95	3.11
Soil texture	Sl	Ts	Sl
t Height [m]	20.00	20.00	28.00
t1 Height [m]	14.00	7.00	16.50
t2 Height [m]	8.00	4.00	6.00
t3 Height [m]	n/a	n/a	n/a
Shrub Height [m]	2.50	2.30	3.00
Herb Height [m]	1.00	0.70	1.00
Moss Height [m]	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1
Vegetation Cover [Londo]	10	10	10
t Cover [%]	139.08	104.08	61.08
t1 Cover [%]	0.50	64.25	126.08
t2 Cover [%]	3.42	17.00	13.17
t3 Cover [%]	0	0	0
Shrub Cover [%]	1.25	6.50	44.92
Herb Cover [%]	79.33	3.00	11.92
Moss Cover [%]	n/a	n/a	n/a
Juvenil Cover [Londo]	n/a	a2	0.7
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a
Carapa grandiflora	3	3	2
Symphonia globulifera	r1	0.7	3
Alchornea hirtella	r1	1.2	p2
Asplenium dregeanum	r1	a1	m2
Asplenium sp. IV	p1	a2	r1
Strombosia scheffleri	6	2	
Cleistanthus polystachyus		6	3
Senegalia montigena		3	r1
Chassalia subochreata		r1	3
Myrianthus holstii		r1	p1
Dracaena laxissima		p1	p1
Celtis gomphophylla		p2	p2
Culcasia falcifolia		p1	r1
Apodytes dimidiata	r1		r1
Parinari excellsa		1	
Astropanax goetzenii		r2	
Oxyanthus speciosus		p4	
Asplenium sp. VI		p1	
Dryopteris sp. IX		a2	
Vepris nobilis		r2	
Pleiocarpa pycnantha		r1	
Pteris cf. auquieri		a2	
Celosia sp.		p1	
Blotiella cf. glabra		r1	
Jasminum sp.		r1	

Table 3.67: *Cleistanthus polystachyus-Carapa grandiflora-Senegalia montigena* community (continued)

Sample Site / Species	69_{NBw}	52_{NGs}	76_{NGk}
Allophylus cf. pseudopaniculatus		p1	
Mimulopsis solmsii	5+		
Shirakiopsis elliptica	3		
Sericostachys scandens	2		
Polyscias fulva	1.2		
Begonia meyeri-johannis	p1		
Urera trinervis	p1		
Coccinia mildbraedii	p1		
Clerodendrum johnstonii	p1		
Piper capense	r1		
Asplenium cf. friesiorum	p1		
Rubus cf. apetalus	r1		
Dichanthelium cf. hillebrandianum	p1		
Mimulopsis arborescens	p2		
Celosia elegantissima	p1		
Gouania longispicata	r2		
Entandrophragma excelsum	r1		
Allophylus pseudopaniculatus	p1		
Asplenium cf. christii	r1		
Impatiens niamniamensis	p1		
Asplenium sp. XXXIII	p1		
Rubus sp. III	r1		
Aframomum cf. mala	p1		
Solanum terminale	r1		
Garcinia volkensii	r1		
Tabernaemontana stapfiana	r2		
Rytigynia cf. bagshawei var. lebrunii	r2		
Syzygium parvifolium			4
cf. Syzygium sp.			3
Harungana montana			2
Lasianthus kilimandscharicus			2
Microcos mildbraedii			0.7
Ocotea usambarensis			r2
Asplenium sandersonii			m1
Macaranga kilimandscharica			r1
Allophylus chaunostachys			r1
Cassipourea ndando			p1
Xymalos monospora			r1
Asplenium cf. gemmiferum			p1
Coffea eugenioides			r1
Gambeya gorungosana			p2
Loxogramme lanceolata			r1
Chlorophytum comosum			r1
Psychotria cf. parvistipulata			p1
Arthropteris cf. monocarpa			p2
Hymenophyllum triangulare			p1
Asplenium sp. XL			p1
Cincinnobotrys speciosa			p1
Commelina sp. I			p1
Agelaea pentagyna			p1
Pentadesma reyndersii			p4
Rhodobryum keniae			m1
Rytigynia sp. VII			r1

Table 3.67: *Cleistanthus polystachyus-Carapa grandiflora-Senegalia montigena* community (continued)

Sample Site / Species	69_{NBw}	52_{NGs}	76_{NGk}
Haplopteris guineensis			p1
Gen. indet. spec. indet. XXI			p4

Further species in the samples: **52_{NGs}**: Gen. indet. spec. indet. CXXXVIII p1; Gen. indet. spec. indet. CXXXIX r1; Apocynaceae sp. IV p1; **69_{NBw}**: Woodsiaceae sp. I 0,7; Gen. indet. spec. indet. XXXVII r1; Poaceae sp. V p1; Gen. indet. spec. indet. XVI r1; Gen. indet. spec. indet. XXXIII r1; Gen. indet. spec. indet. XXXIV r1; Gen. indet. spec. indet. XXXV r1; Gen. indet. spec. indet. XI p1; **76_{NGk}**: Gen. indet. spec. indet. LXVIII 2; Bryopsida sp. m1; Gen. indet. spec. indet. XXI p4

3.2.33 *Strombosia scheffleri-Carapa grandiflora-Mimulopsis solmsii* Community

Fuzzy k-means cluster number: M25

UPGMA, local cut information level: 58%

Plots: 69_{NBw}

Locations: Nyungwe, Bweyeye

M25	69_{NBw}	52_{NGs}	54_{NGs}	76_{NGk}
69_{NBw}	0	0.74	0.69	0.89
52_{NGs}		0	0.79	0.68
54_{NGs}			0	0.86
76_{NGk}				0

Table 3.68: Bray-Curtis dissimilarities between the samples discussed.

M25	69_{NBw}	52_{NGs}	54_{NGs}	76_{NGk}
69_{NBw}	0	15.21	15.02	19.99
52_{NGs}		0	0.19	9.78
54_{NGs}			0	9.87
76_{NGk}				0

Table 3.69: Geographic distances between the samples discused in km.

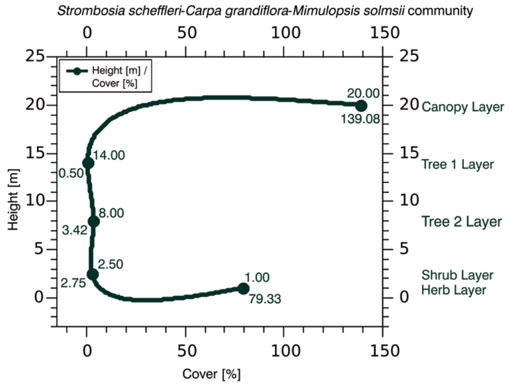


Figure 3.41: Cover-Height relation of the community recovered near Bweyeye; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

The preceding paragraph is connected directly to plot 69_{NBw}, which holds vegetation of quite a similar species composition. When it comes to classification, the same is very much valid here as discussed exhaustively in previous paragraphs. In terms of a combination of plot 52_{NGs} and the plot at Bweyeye, a negative decision has to be taken. A bit more similar to the plot at hand are sites 54_{NGs} and 84_{Gw}. The similarity to the site at Gishwati Forest is based on the high abundances of only a few species, and a combination of the plots will not be discussed any further at this point. With plot 54_{NGs}, on the other hand, the known predicament in establishing a syntaxonomic unit unfolds again. Quite reluctantly, a merging will not be undertaken for plot 69_{NBw}. The noticeable abundance of *Myrianthus holstii* alone might not have been enough here, since it is not uncommon in the vegetation surveyed, but it is still not forming monotonous stands. It is solely on the grounds of the peculiarity of the herb layer that the plots remain parted. The high abundance of *Mimulopsis solmsii* and the low concordance of the remaining herbal species inventory call for separate communities. On the matter of secondary versus climax vegetation, the decision has to be adjourned until more comprehensive data has been collected. Though situated on opposite sides of Nyungwe National Park, both stands are closely related realisations of vegetation types of lower and mid-level cloud forests.

Again, the class Strombosio-Parinarietea seems applicable. Any further classification that places the plot into an existing system is not possible. As so often, the community found has to be given a temporary name: *Strombosia scheffleri-Carapa grandiflora-Mimulopsis solmsii* community.

Site 69 faces WSW, and the vegetation has a maximum head of 20 m roots in sandy soils with a drillable soil depth of 1.27 m and a pH of 3.17. The mean annual temperature is 16.00°C. The three tree layers present, cover a shrub layer which is barely existent and a quite dense herb layer.

Table 3.70: *Strombosia scheffleri-Carapa grandiflora-Mimulopsis solmsii* community

Sample Site / Species	^{69}NBw	^{52}NGs	^{76}NGk
Exposition	WSW	SO	SO
Inclination [°]	30	30	46
Position / Relief	HU	HM	KH
Precipitation / a [mm]	1865	2201	2530
Elevation a.s.l. [m]	1915	1965	1849
T S_{60} [°C]	16.00	17.70	17.00
pH	3.17	2.95	3.11
Soil texture	Sl	Ts	Sl
t Height [m]	20.00	20.00	28.00
t1 Height [m]	14.00	7.00	16.50
t2 Height [m]	8.00	4.00	6.00
t3 Height [m]	n/a	n/a	n/a
Shrub Height [m]	2.50	2.30	3.00
Herb Height [m]	1.00	0.70	1.00
Moss Height [m]	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1
Vegetation Cover [Londo]	10	10	10
t Cover [%]	139.08	104.08	61.08
t1 Cover [%]	0.50	64.25	126.08
t2 Cover [%]	3.42	17.00	13.17
t3 Cover [%]	0	0	0
Shrub Cover [%]	1.25	6.50	44.92
Herb Cover [%]	79.33	3.00	11.92
Moss Cover [%]	n/a	n/a	n/a
Juvenil Cover [Londo]	n/a	a2	0.7
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a
Carapa grandiflora	3	3	2
Symphonia globulifera	r1	0.7	3
Alchornea hirtella	r1	1.2	p2
Asplenium dregeanum	r1	a1	m2
Asplenium sp. IV	p1	a2	r1
Strombosia scheffleri	6	2	
Cleistanthus polystachyus		6	3
Senegalia montigena		3	r1
Chassalia subochreata		r1	3
Myrianthus holstii		r1	p1
Dracaena laxissima		p1	p1
Celtis gomphophylla		p2	p2
Culcasia falcifolia		p1	r1
Apodytes dimidiata	r1		r1
Parinari excellsa		1	

Table 3.70: *Strombosia scheffleri-Carapa grandiflora-Mimulopsis solmsii* community (continued)

Sample Site / Species	^{69}NBw	^{52}NGs	^{76}NGk
Astropanax goetzenii		r2	
Oxyanthus speciosus		p4	
Asplenium sp. VI		p1	
Dryopteris sp. IX		a2	
Vepris nobilis		r2	
Pleiocarpa pycnantha		r1	
Pteris cf. auquieri		a2	
Celosia sp.		p1	
Blotiella cf. glabra		r1	
Jasminum sp.		r1	
Allophylus cf. pseudopaniculatus		p1	
Mimulopsis solmsii	5+		
Shirakiopsis elliptica	3		
Sericostachys scandens	2		
Polyscias fulva	1.2		
Begonia meyeri-johannis	p1		
Urera trinervis	p1		
Coccinia mildbraedii	p1		
Clerodendrum johnstonii	p1		
Piper capense	r1		
Asplenium cf. friesiorum	p1		
Rubus cf. apetalus	r1		
Dichanthelium cf. hillebrandianum	p1		
Mimulopsis arborescens	p2		
Celosia elegantissima	p1		
Gouania longispicata	r2		
Entandrophragma excelsum	r1		
Allophylus pseudopaniculatus	p1		
Asplenium cf. christii	r1		
Impatiens niamniamensis	p1		
Asplenium sp. XXXIII	p1		
Rubus sp. III	r1		
Aframomum cf. mala	p1		
Solanum terminale	r1		
Garcinia volkensii	r1		
Tabernaemontana stapfiana	r2		
Rytigynia cf. bagshawei var. lebrunii	r2		
Syzygium parvifolium			4
cf. Syzygium sp.			3
Harungana montana			2
Lasianthus kilimandscharicus			2
Microcos mildbraedii			0.7

Table 3.70: *Strombosia scheffleri-Carapa grandiflora-Mimulopsis solmsii* community (continued)

Sample Site / Species	69_{NBw}	52_{NGs}	76_{NGk}
Ocotea usambarensis			r2
Asplenium sandersonii			m1
Macaranga kilimandscharica			r1
Allophylus chaunostachys			r1
Cassipourea ndando			p1
Xymalos monospora			r1
Asplenium cf. gemmiferum			p1
Coffea eugenioides			r1
Gambeya gorungosana			p2
Loxogramme lanceolata			r1
Chlorophytum comosum			r1
Psychotria cf. parvistipulata			p1
Arthropteris cf. monocarpa			p2
Hymenophyllum triangulare			p1
Asplenium sp. XL			p1
Cincinnobotrys speciosa			p1
Commelina sp. I			p1
Agelaea pentagyna			p1
Pentadesma reyndersii			p4
Rhodobryum keniae			m1
Rytigynia sp. VII			r1
Haplopteris guineensis			p1

Further species in the samples: **52_{NGs}**: Gen. indet. spec. indet. CXXXVIII p1; Gen. indet. spec. indet. CXXXIX r1; Apocynaceae sp. IV p1; **69_{NBw}**: Woodsiaceae sp. I 0,7; Gen. indet. spec. indet. XXXVII r1; Poaceae sp. V p1; Gen. indet. spec. indet. XVI r1; Gen. indet. spec. indet. XXXIII r1; Gen. indet. spec. indet. XXXIV r1; Gen. indet. spec. indet. XXXV r1; Gen. indet. spec. indet. XI p1; **76_{NGk}**: Gen. indet. spec. indet. LXVIII 2; Bryopsida sp. m1; Gen. indet. spec. indet. XXI p4;

3.2.34 Macarango-Psychotrietum mahonii Habiyaremye (1997)

UPGMA, local cut information level: 83%

Fuzzy k-means cluster number: M35

Plots: 9_{NU}, 11_{NU}, 32_{NB}, 34_{NGa}, 62_{NR}, 64_{NR}, 65_{NR}, 71_{NM}, 72_{NM}, 73_{NM}, 74_{NM}, 94_{Gw}

Locations: Uwinka, Bigugu, Ruzizi, Musebeya, Gishwati

M35	9_{NU}	11_{NU}	32_{NB}	34_{NGa}	62_{NR}	64_{NR}	65_{NR}	71_{NM}	72_{NM}	73_{NM}	74_{NM}	94_{Gw}
9_{NU}	0	0.33	0.49	0.43	0.4	0.29	0.42	0.37	0.45	0.43	0.26	0.5
11_{NU}		0	0.47	0.51	0.43	0.43	0.48	0.36	0.43	0.49	0.3	0.5
32_{NB}			0	0.59	0.54	0.55	0.58	0.48	0.58	0.48	0.47	0.6
34_{NGa}				0	0.52	0.49	0.54	0.49	0.56	0.53	0.41	0.59
62_{NR}					0	0.48	0.49	0.44	0.5	0.47	0.39	0.53
64_{NR}						0	0.49	0.44	0.53	0.5	0.4	0.55
65_{NR}							0	0.49	0.53	0.53	0.43	0.54
71_{NM}								0	0.37	0.45	0.37	0.55
72_{NM}									0	0.49	0.45	0.57
73_{NM}										0	0.4	0.58
74_{NM}											0	0.44
94_{Gw}												0

Table 3.71: Bray-Curtis dissimilarities between the samples discussed.

M35	9_{NU}	11_{NU}	32_{NB}	34_{NGa}	62_{NR}	64_{NR}	65_{NR}	71_{NM}	72_{NM}	73_{NM}	74_{NM}	94_{Gw}
9_{NU}	0	0.39	5.06	31.05	17.13	14.24	14.79	22.89	20.7	20.74	23.13	75.02
11_{NU}		0	5.43	31.32	17.4	14.5	15.04	23.25	21.07	21.1	23.48	75.15
32_{NB}			0	29.50	12.97	10.12	10.76	17.88	15.65	15.68	18.12	71.92
34_{NGa}				0	37.24	35.64	36.29	33.24	30.84	30.88	33.51	93.82
62_{NR}					0	2.9	2.38	9.67	9.51	9.5	9.72	59.39
64_{NR}						0	0.7	11.13	10.25	10.26	11.25	62
65_{NR}							0	11.16	10.44	10.45	11.26	61.32
71_{NM}								0	2.76	2.72	0.3	60.66
72_{NM}									0	0.04	3.06	63.2
73_{NM}										0	3.02	63.16
74_{NM}											0	60.38
94_{Gw}												0

Table 3.72: Geographic distances between the samples discused in km.

With this cluster, there are some differences between the UPGMA and the FCM-NC derived results. When cutting the UPGMA dendrogram locally at the 84% information level, a visually apparent cluster consisting of plots 9_{NU}, 74_{NM}, 11_{NU}, 71_{NM}, 64_{NR}, 62_{NR}, 73_{NM}, 72_{NM}, 32_{NB} and 94_{Gw} is obtained. Here, the fuzzy c-means includes plot 65_{NR} but excludes plots 32_{NB} and 73_{NM} from a comparable cluster. The excluded plots are separated into another cluster which then also includes plot 70_{NM}. As discussed for cluster M2, plot 65_{NR} is remarkably similar to plot 63_{NR}. Nevertheless, FCM-NC includes plot 65_{NR} in cluster M35 with a membership of about 76%. Since every solution derived from the numerical methods contains some truth, the results will be discussed jointly. Though homogenous clusters are intended and the algorithms underlying the methods are designed to keep the internal cluster variance to a minimum, enabling ecological thought for a moment tells us that numerical homogeneity in tropical vegetation might be a relative ingredient in concocting a vegetation community. Since the cluster constructed by FCM-NC (M30) containing plots 32_{NB} and 73_{NM} also contains plot 70_{NM}, the feasibility of a combined cluster will be discussed accordingly.

Before reasoning as to the composition of the cluster, some information on the environmental and vegetational parameters measured shall be given. With very few exceptions, the exposition of the sites ranges between west via south to the east. Only three sites face NE, WNW and NW, respectively. All sites are situated at the mid-level of the montane rain forest. Their respective soil is either sandy or consists of clay for the larger percentage. The pH value can get as low as 2.70 and does not exceed 3.94. The drillable soil depths can get as low as 0.60 m but generally exceed one metre. In most of the sites, three tree layers can be noticed with a canopy not passing 30 metres. The ground cover of the herb and shrub layer differs between barely developed to dense.

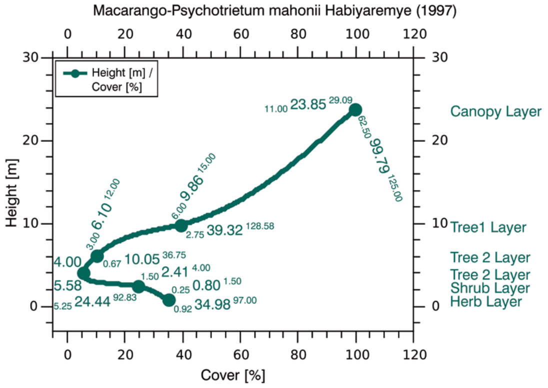


Figure 3.42: Cover-Height relation of the community recovered at the astern parts of Nyungwe, close to Uwinka and in Gishwati forest; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Macaranga kilimandscharica is by far the most predominant in the canopy of all plots, thus bridging the difference in vegetation composition between the eastern and western parts of Nyungwe Forest. Though far less abundant, the same is true for *Chassalia subochreata*. Not occurring in the Gishwati plot, *Syzygium parvifolium* and *Psychotria mahonii* are present at Uwinka, Bigugu, Ruzizi and Musebeya. Except for the plot on the foot of Mt. Bigugu, one plot at Ruzizi and the plot in Gishwati, *Begonia meyeri-johannis* was found in all plots. *Impatiens purpureo-violacea* was found in half of the sample plots, excluding Gishwati, Bigugu and Ruzizi. With the exception of Gishwati and two plots at Ruzizi, *Sericostachys scandens* has been found in all plots; at one site in Musebeya it even covers over 77%. An unidentified species of *Dryopteris sp. IX* was found in most plots at Ruzizi and Musebeya.

According to Schmitz (1988), the vegetation found belongs to the “forêts ombrophiles et secondaires de montagne”. Fischer (1996) reported *Macaranga* dominated secondary forests in the Kahuzi-Biega National Park, which offer some similarities. For the eastern part of Nyungwe Forest within the middle altitudes, Fischer & Hinkel (1993) described secondary *Macaranga* dominated forests. Habiyayremye (1997) characterised these as *Macarango-Psychotrietum mahonii*. Despite *Psychotria* being present in only small abundance, this classification could be maintained. A modification emphasising *Chassalia subochreata* and *Begonia meyeri-johannis*, and perhaps also *Sericostachys scandens*, would be worth considering. A *Macaranga kilimandscharica-Chassalia subochreata-Begonia meyeri-johannis* community would be an example. This community could then be integrated into the order *Polyscietalia fulvae* Lebrun et Gilbert 1954.

Though the membership degree of plots 32_{NB} and 73_{NM} for cluster M35 is only about 11% and 0.007%, respectively, the establishment of a separate cluster does not seem necessary. Including plot 70_{NM} into said extra cluster would make it quite dense, but neither compositional variety nor the UPGMA results would explain the allocation.

In a somewhat arbitrary decision, the site at Musebeya has been included into cluster M28. This ruling puts emphasis on the results stemming from UPGMA and takes the slightly better fit of the species composition with the other plots into consideration. For the stands discussed in this passage, the UPGMA derived cluster with the inclusion of plot 65_{NR} seems to be best suited to describe the vegetation at the sampling sites. Another addition, which is warranted by sufficient similarities and species co-occurrences, is plot 34_{NGa}. This site has already been discussed under 3.2.13. The UPGMA results show a clear cluster comprising two sites in the Gishwati Forest and the site at Gahurizo. The occurrence of *Macaranga*, the even higher number of co-occurrences, the quite low dissimilarities and the fact that FCM-NC gives plot 34_{NGa} secondary membership to cluster M35 provide enough reason beyond arbitrariness to include the site at Gahurizo into the Macarango-Psychotrietum mahonii.

Table 3.73: Macarango-Psychotrietum mahonii Habiyaremye (1997)

Sample Site / Species	9_{NU}	11_{NU}	32_{NB}	62_{NR}	64_{NR}	71_{NM}
Exposition	S	NE	0	n/a	WNW	SE
Inclination [°]	11	9	0	n/a	20	31
Position / Relief	HM	HO	HM	n/a	KH	HM
Precipitation / a [mm]	1876	1881	1791	1655	1715	1261
Elevation a.s.l. [m]	2449	2498	2545	2323	2327	2524
T S_{60} [°C]	14.00	13.00	13.00	15.00	15.00	14.50
pH	2.70	2.76	2.74	3.56	3.22	2.91
Soil texture	Ts	Ts	Sl	Ts	St	Ts
t Height [m]	24.24	22	21.6	11	22	29.09
t1 Height [m]	6	14	9	8	13.5	8
t2 Height [m]	4	8	6	4	6	6
t3 Height [m]	n/a	n/a	n/a	n/a	n/a	n/a
Shrub Height [m]	2.5	2	3	1.5	2.5	2.3
Herb Height [m]	1.5	0.6	0.25	1	1.5	1.1
Moss Height [m]	n/a	n/a	n/a	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	1	0	n/a	1	1	1
Vegetation Cover [Londo]	10	10	10	10	10	10
t Cover [%]	80.25	95.42	125.00	113.33	105.42	114.58
t1 Cover [%]	23.33	20.33	56.08	55.00	3.33	48.00
t2 Cover [%]	2.25	0.67	23.50	2.33	3.08	1.17
t3 Cover [%]	0	0	0	0	0	0
Shrub Cover [%]	6.33	13.42	65.00	12.33	14.08	10.42
Herb Cover [%]	23.67	43.67	7.50	7.25	77.67	41.86
Moss Cover [%]	n/a	n/a	n/a	n/a	n/a	n/a
Juvenil Cover [Londo]	n/a	2	p2	a2	n/a	a1
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	n/a	n/a	n/a
Macaranga kilimandscharica	10	9	9	10	10	10
Chassalia subochreata		0.7	6	1.2		0.7
Sericostachys scandens	p1	r1	p2	p1		p4
Begonia meyeri-johannis	1.2	p1		p1	3	p1
Psychotria mahonii	p2	p2	p2		p1	3
Syzygium parvifolium	p1	0.7	1.2		0.7	2
Dryopteris sp. IX				a2	r1	p1
Allophylus chaunostachys	r1		p2		r1	p1
Asplenium sandersonii		p2		p1		a1
Impatiens purpureo-violacea	p1	1.2				0.7
Carapa grandiflora		1.2		p1	p1	
Urera hypselodendron	r1		r1		p1	
Salacia erecta				r1		p2
Blotiella glabra			p2			
Asplenium sp. IV		p1				

Table 3.73: Macarango-Psychotrietum mahonii HABIYAREMYE (1997) (continued)

Sample Site / Species	9_{NU}	11_{NU}	32_{NB}	62_{NR}	64_{NR}	71_{NM}
cf. Isachne mauritiana						0.7
Symphonia globulifera				r1	r1	
Dryopteris sp. XII						
Mikaniopsis usambarensis						
Impatiens gesneroidea	p2	p2			p4	
Embelia libeniana	p2	p4		p1		
Embelia schimperi			r1			r1
Xymalos monospora					p1	
Monanthotaxis orophila					p1	
Asplenium sp. VI				p1		
Coleus cf. melleri						p1
Polyscias fulva				p1		
Galiniera saxifraga						
Myrsine melanophloeos			2			r1
Parinari excellsa				p1		
Keetia gueinzii	p1		p2			
Oxyanthus speciosus	p1		p1			
Mikaniopsis tedliei	p1		p1			
Rytigynia kigeziensis	p1	p1				
Pavetta rwandensis		p1	p2			
Myrianthus holstii				7		
Astropanax goetzenii		r1				
Pteridium aquilinum	r1				p2	
Asplenium cf. friesiorum						a1
Ficalhoa laurifolia				p2		r1
Blotiella cf. bouxiniana		r1		p1		
Psychotria peduncularis						
Dalbergia lactea						
Rytigynia sp. VI						r1
Alchornea hirtella						
Asplenium friesiorum					p1	
Rubus cf. apetalus					p1	
Liparis bowkeri						
Mikania cordata	p1					
Asplenium sp. II		r1				
Mikaniopsis sp.		0.7				
Mimulopsis excellens			0.7			
Dracaena laxissima					p1	
Lasianthus kilimandscharicus						
Oxyanthus troupinii						
Coleus melleri						
Blotiella sp. III	4					

Table 3.73: Macarango-Psychotrietum mahonii HABIYAREMYE (1997) (continued)

Sample Site / Species	9_{NU}	11_{NU}	32_{NB}	62_{NR}	64_{NR}	71_{NM}
Blotiella cf. stipitata	0.7					
Blotiella bouxiniana	p2					
cf. Rourea thomsonii	r1					
Stellaria sennii	p4					
Rubus pinnatus	p2					
Crassocephalum sp. I	r1					
Blotiella sp. V	r2					
Clutia abyssinica		r1				
Stephania abyssinica		r1				
Mimulopsis solmsii		r1				
Pavetta bagshawei		p1				
Impatiens cf. warburgiana		r1				
Crassocephalum rubens		r1				
Cyperus sp.		p1				
Mikaniopsis sp. I		r1				
Asplenium dregeanum		p1				
Dryopteris sp. II		r1				
Maytenus acuminata			4			
Peddiea orophila			r1			
Olea capensis ssp. hochstetteri			?			
Apodytes dimidiata			r1			
Rhipidoglossum bilobatum			r1			
Clerodendrum johnstonii				p1		
Diplazium sp. VI				a2		
Asplenium sp. XVI				p1		
Pilea bambuseti					4	
Blotiella sp. IV					1.2	
Coccinia mildbraedii					p1	
Neoboutonia macrocalyx					p1	
Asplenium mannii					r1	
Erythrococca atrovirens					r1	
Mikania sp. III					p1	
Diplazium sp. V					p1	
Asplenium sp. XXVIII					p1	
Harungana montana						1.2
Blotiella cf. glabra						p2
Toddalia sp.						r1
cf. Asplenium mannii						a1
Gynura scandens						
Vittaria sp.						
Impatiens niamniamensis						
Asplenium sp. XXXVI						

Table 3.73: Macarango-Psychotrietum mahonii HABIYAREMYE (1997) (continued)

Sample Site / Species	9_{NU}	11_{NU}	32_{NB}	62_{NR}	64_{NR}	71_{NM}
Mimulopsis sp.						
Elaphoglossum acrostichoides						
Solanum sp.						
Asplenium cf. bugoiense						
Asplenium bugoiense						
Balthasaria schliebenii						
Otiophora pauciflora ssp. burttii						
Ilex mitis						
Mimulopsis sp. I						
Cyperus sp. IV						
Dryopteris sp. XI						
Stephania cf. cyanantha						
Mikania sp. V						
Cuscuta sp.						
Psychotria sp.						
Albizia gummifera						
Diplazium sp. II						
Culcasia sp.						
cf. Commelina sp.						
Chlorophytum sp.						
Ficus sp. IX						
Lindackeria sp.						
Tabernaemontana sp.						
Clerodendrum buchananii						
Loeseneriella africana						
Smilax anceps						
Allophylus pseudopaniculatus						
Asplenium sp. XXII						
Asplenium sp. XXIII						
Gouania longispicata						
Strombosia scheffleri						
Isachne mauritiana						
Maesa lanceolata						
Olinia rochetiana						
Drymaria cf. cordata						
Asplenium mildbraedii						
Ipomoea involucrata						
Rubus cf. steudneri						
cf. Asplenium friesiorum						
Pycnostachys meyeri						
Rytigynia sp. IV						
Dichanthelium hillebrandianum						

Table 3.73: Macarango-Psychotrietum mahonii Habiyaremye (1997)(continued)

Sample Site / Species	^{72}NM	^{73}NM	^{74}NM	^{94}Gw	^{65}NR	^{34}NGa
Exposition	W	NW	S	SE	SE	E
Inclination [°]	27.5	33	26	32	10	30
Position / Relief	HM	HM	HM	HO	KR	HO
Precipitation / a [mm]	1314	1314	1261	1389	1708	1675
Elevation a.s.l. [m]	2469	2477	2520	2242	2370	2512
T S_{60} [°C]	14.30	14.00	13.70	16.00	15.00	14.5
pH	3.16	2.82	3.34	3.88	3.94	3.15
Soil texture	Sl	Ts	Ts	Sl	Ts	Sl
t Height [m]	26.98	27.16	25.36	27.5	24.3	20.94
t1 Height [m]	9	11	6	15	9	6
t2 Height [m]	3	6	n/a	12	6	n/a
t3 Height [m]	n/a	n/a	n/a	n/a	n/a	n/a
Shrub Height [m]	1.8	2.3	2.3	2.3	4	2.3
Herb Height [m]	0.4	0.6	0.6	0.7	0.5	1
Moss Height [m]	n/a	n/a	n/a	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1	0	1	1
Vegetation Cover [Londo]	10	10	10	10	10	10
t Cover [%]	116.33	94.83	93.75	62.50	96.25	97.5
t1 Cover [%]	28.50	61.08	2.75	128.58	5.50	11.08
t2 Cover [%]	1.92	16.42	2.08	36.75	20.42	0
t3 Cover [%]	0	0	0	0	0	0
Shrub Cover [%]	9.75	32.00	5.25	7.41	92.83	2.5
Herb Cover [%]	76.33	7.42	97.00	2	0.92	101.67
Moss Cover [%]	n/a	n/a	n/a	n/a	n/a	n/a
Juvenil Cover [Londo]	p1	a2	p1	p1	p2	p1
Juvenil Shrub Cover [Londo]	n/a	p1	n/a	p1	n/a	n/a
Macaranga kilimandscharica	10	10	9	9	10	10
Chassalia subochreata	0.7	3	r1	p4	p4	r1
Sericostachys scandens	r1	8	0.7			p4
Begonia meyeri-johannis	p1	p4	p1			m2
Psychotria mahonii	2	r1			r1	p1
Syzygium parvifolium	p1				r1	r1
Dryopteris sp. IX	r1	p1	p1			
Allophylus chaunostachys		p1				r1
Asplenium sandersonii	p1	p1				
Impatiens purpureo-violacea	7	p1				
Carapa grandiflora				r1	p1	
Urera hypselodendron	p2				p2	
Salacia erecta	p1	p1				
Blotiella glabra	p2	p1	p1			
Asplenium sp. IV	p2	p1	r1			

Table 3.73: Macarango-Psychotrietum mahonii Habiyaremye (1997)(continued)

Sample Site / Species	^{72}NM	^{73}NM	^{74}NM	^{94}Gw	^{65}NR	^{34}NGa
cf. Isachne mauritiana	p1	p1		p1		
Symphonia globulifera				6	r1	
Dryopteris sp. XII	r1	p1	p1			r1
Mikaniopsis usambarensis	p2	p1	p1		p1	
Impatiens gesneroidea						
Embelia libeniana						
Embelia schimperi		p1				
Xymalos monospora		r1		p4		
Monanthotaxis orophila	p2	p1				
Asplenium sp. VI	p2	p2				
Coleus cf. melleri	r1	r1				
Polyscias fulva				r2	r1	
Galiniera saxifraga		r1	p2			p2
Myrsine melanophloeos						r1
Parinari excellsa				p1		
Keetia gueinzii						
Oxyanthus speciosus						
Mikaniopsis tedliei						
Rytigynia kigeziensis						
Pavetta rwandensis						
Myrianthus holstii				r1		
Astropanax goetzenii	p1					
Pteridium aquilinum						
Asplenium cf. friesiorum			p1			
Ficalhoa laurifolia						
Blotiella cf. bouxiniana						
Psychotria peduncularis	0.7			2		
Dalbergia lactea	2	p1				
Rytigynia sp. VI		p1				
Alchornea hirtella				r1	10	
Asplenium friesiorum						m4
Rubus cf. apetalus						p2
Liparis bowkeri				p1	p1	
Mikania cordata						
Asplenium sp. II						
Mikaniopsis sp.						
Mimulopsis excellens						
Dracaena laxissima						
Lasianthus kilimandscharicus	p1					
Oxyanthus troupinii		r1				
Coleus melleri				p1		
Blotiella sp. III						

Table 3.73: Macarango-Psychotrietum mahonii HABIYAREMYE (1997)(continued)

Sample Site / Species	72NM	73NM	74NM	94Gw	65NR	34NGa
Blotiella cf. stipitata						
Blotiella bouxiniana						
cf. Rourea thomsonii						
Stellaria sennii						
Rubus pinnatus						
Crassocephalum sp. I						
Blotiella sp. V						
Clutia abyssinica						
Stephania abyssinica						
Mimulopsis solmsii						
Pavetta bagshawei						
Impatiens cf. warburgiana						
Crassocephalum rubens						
Cyperus sp.						
Mikaniopsis sp. I						
Asplenium dregeanum						
Dryopteris sp. II						
Maytenus acuminata						
Peddiea orophila						
Olea capensis ssp. hochstetteri						
Apodytes dimidiata						
Rhipidoglossum bilobatum						
Clerodendrum johnstonii						
Diplazium sp. VI						
Asplenium sp. XVI						
Pilea bambuseti						
Blotiella sp. IV						
Coccinia mildbraedii						
Neoboutonia macrocalyx						
Asplenium mannii						
Erythrococca atrovirens						
Mikania sp. III						
Diplazium sp. V						
Asplenium sp. XXVIII						
Harungana montana						
Blotiella cf. glabra						
Toddalia sp.						
cf. Asplenium mannii						
Gynura scandens	p1					
Vittaria sp.	r1					
Impatiens niamniamensis	p1					
Asplenium sp. XXXVI	p2					

Table 3.73: Macarango-Psychotrietum mahonii HABIYAREMYE (1997)(continued)

Sample Site / Species	^{72}NM	^{73}NM	^{74}NM	^{94}Gw	^{65}NR	^{34}NGa
Mimulopsis sp.	p1					
Elaphoglossum acrostichoides	p1					
Solanum sp.	p1					
Asplenium cf. bugoiense	p1					
Asplenium bugoiense		p1				
Balthasaria schliebenii		p1				
Otiophora pauciflora ssp. burttii		p1				
Ilex mitis		r1				
Mimulopsis sp. I		p1				
Cyperus sp. IV		r1				
Dryopteris sp. XI		p1				
Stephania cf. cyanantha		r1				
Mikania sp. V			r1			
Cuscuta sp.			m1			
Psychotria sp.				3		
Albizia gummifera				2		
Diplazium sp. II				r1		
Culcasia sp.				p1		
cf. Commelina sp.				p1		
Chlorophytum sp.				p1		
Ficus sp. IX				r1		
Lindackeria sp.				r1		
Tabernaemontana sp.				r2		
Clerodendrum buchananii				p1		
Loeseneriella africana				r1		
Smilax anceps				p4		
Allophylus pseudopaniculatus				r1		
Asplenium sp. XXII				p1		
Asplenium sp. XXIII				p1		
Gouania longispicata				r1		
Strombosia scheffleri					r1	
Isachne mauritiana						9
Maesa lanceolata						1.2
Olinia rochetiana						r1
Drymaria cf. cordata						m1
Asplenium mildbraedii						m2
Ipomoea involucrata						r1
Rubus cf. steudneri						p1
cf. Asplenium friesiorum						p2
Pycnostachys meyeri						r1
Rytigynia sp. IV						p1
Dichanthelium hillebrandianum						p1

Table 3.73 (continued): Further species in the samples: **11_{NU}**: Polypodiales sp. X r1; **32_{NB}**: Rubiaceae sp. XXIII 3; Rubiaceae sp. XXII p1; **62_{NR}**: Gen. indet. spec. indet. CLXXVII r1; **64_{NR}**: Polypodiales sp. XXIV r1; **71_{NM}**: Acanthaceae sp. VI 2; Polypodiales sp. IX p1; Gen. indet. spec. indet. XL r1; **72_{NM}**: Asteraceae sp. III r1; **73_{NM}**: Gen. indet. spec. indet. XLVI r1; Gen. indet. spec. indet. LIII p1; Gen. indet. spec. indet. XLI r1; **74_{NM}**: Acanthaceae sp. VII 10; Gen. indet. spec. indet. LXI r1; Cucurbitaceae sp. VIII r1; **94_{Gw}**: Polypodiales sp. I p1; Asteraceae sp. VIII p2; Gen. indet. spec. indet. IV r1; Rubiaceae sp. XXI r1; Rubiaceae sp. XX p1; **34_{NGa}**: Caryophyllaceae sp. I r1

3.2.35 Neoboutonia macrocalyx-Macaranga Low-Stemmed Secondary Community

UPGMA, local cut information level: 62%
Fuzzy k-means cluster number: Noise
Plots: 37NGa
Locations: Nyungwe, Gahurizo

Noise	37_{NGa}	41_{NK}	61_{NR}
37_{NGa}	0	0.83	0.68
41_{NK}		0	0.79
61_{NR}			0

Table 3.74: Bray-Curtis dissimilarities between the samples discussed.

Noise	37_{NGa}	41_{NK}	61_{NR}
37_{NGa}	0	14.5	37.14
41_{NK}		0	24.35
61_{NR}			0

Table 3.75: Geographic distances between the samples discused in km.

Site 37_{NGa} faces WSW and is positioned at the medium level of the montane rain forest. The mean annual temperature reaches 14.00°C, and the pH of the sandy and rather shallow soil is 3.35. While the canopy only reaches 9 m in height, a second tree layer can still be perceived. Ultimately, the shrub and herb layer are not very well developed. The *Neoboutonia macrocalyx* dominated site at Gahurizo in Nyungwe National Park has been placed close to plot 61_{NR} by UPGMA, and plot 43_{NK} shows some similarities according to the Bray-Curtis index. Albeit species composition may seem sufficiently similar to merge plots 43_{NK} and 37_{NGa} into the same cluster, a closer look at the morphology of both stands reveals several differences. Dissimilar to the same extent, plot 61_{NR} does not fulfil the requirements to establish a joined community either. Species overlap between the two plots is restricted to only four species. Here, the author will follow the FCM-NC result, which puts site 37_{NGa} into the noise cluster. Within the plot, Macaranga kilimandscharica occurs in a higher proportion. *Xymalos monospora* in the third tree layer adds to the secondary character, as do the occurrences of e.g., *Rubus* cf. *apetalus* and *Begonia meyeri-johannis*. Fischer & Hinkel (1994) described a low-stemmed *Neoboutonia macrocalyx-Polyscias fulva* secondary forest for Gishwati. Species composition and morphology of the site at hand do not fully match the vegetation type described by the authors (IBID.). Thus, another auxiliary vegetation unit–the low-stemmed *Neoboutonia macrocalyx-Macaranga* secondary community–is established here. This community could then be integrated into the Polyscion fulvae Lebrun & Gilbert (1954, p.62).

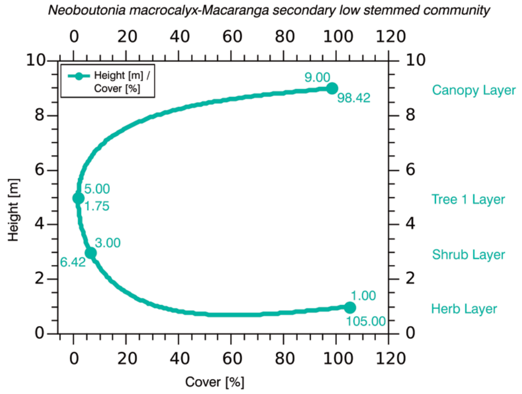


Figure 3.43: Cover-Height relation of the community recovered close to Gahurizo; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Table 3.76: *Neoboutonia macrocalyx*-*Macaranga* secondary community

Sample Site / Species	^{37}NGa	^{61}NR
Exposition	WSW	N
Inclination [°]	40	37.5
Position / Relief	HM	HM
Precipitation / a [mm]	1670	1655
Elevation a.s.l. [m]	2499	2315
T S_{60} [°C]	14.00	14.50
pH	3.35	3.14
Soil texture	Sl	Ts
t Height [m]	9.00	22.25
t1 Height [m]	5.00	7.00
t2 Height [m]	n/a	4.00
t3 Height [m]	n/a	n/a
Shrub Height [m]	3.00	2.30
Herb Height [m]	1.00	0.60
Moss Height [m]	n/a	n/a
Juvenil Height [m]	n/a	n/a
Epiphyts [m/6m]	n/a	1
Vegetation Cover [Londo]	10	10
t Cover [%]	98.42	87.75
t1 Cover [%]	0.25	16.75
t2 Cover [%]	1.50	6.50
t3 Cover [%]	0	0
Shrub Cover [%]	6.42	4.17
Herb Cover [%]	10.50	3.67
Moss Cover [%]	n/a	n/a
Juvenil Cover [Londo]	p1	a2
Juvenil Shrub Cover [Londo]	n/a	p1
Macaranga kilimandscharica	3	3
Begonia meyeri-johannis	p2	a1
Urera hypselodendron	p1	p1
Asplenium sp. VI	p1	p1
Neoboutonia macrocalyx	6	
Chassalia subochreata	r2	
Psychotria mahonii	p1	
Asplenium erectum	p1	
Impatiens gesneroidea	p1	
Mikania cordata	p1	
Allophylus chaunostachys	p1	
Galiniera saxifraga	r1	
Triumfetta cordifolia	p2	
Asplenium mildbraedii	p1	
Ipomoea involucrata	p1	

Table 3.76: *Neoboutonia macrocalyx-Macaranga* secondary community (continued)

Sample Site / Species	^{37}NGa	^{61}NR
Xymalos monospora	p2	
Pilea rivularis	p2	
Drymaria cordata	p1	
Asplenium cf. friesiorum	p1	
Coleus autranii	p1	
Asplenium friesiorum	r1	
Dracaena afromontana	p1	
Rubus cf. steudneri	p1	
Asplenium sp. IV	p1	
Rubus cf. apetalus	p2	
Dichanthelium cf. hillebrandianum	p2	
Pycnostachys meyeri	p1	
Cyperus sp. III	p1	
Pilea bambuseti	a4	
Pteris cf. preussii	p1	
Asplenium gemmascens	p1	
Impatiens cf. burtonii	p1	
Mikania chenopodiifolia	p1	
Basella alba	p1	
Mikania sp. II	p2	
cf. Microglossa sp.	r1	
Carapa grandiflora		1.2
cf. Hippocratea sp.		0.7
Alchornea hirtella		p4
Symphonia globulifera		p1
Astropanax goetzenii		p1
Asplenium sandersonii		p1
Sericostachys scandens		r1
Polyscias fulva		r1
Gynura scandens		p1
Myrianthus holstii		r2
Ilex mitis		r4
Impatiens sp.		r1
Elaphoglossum sp.		p1
Dryopteris sp. IX		a2
Dalbergia lactea		p1
Vittaria sp.		r1
Astropanax abyssinicus		p1
cf. Peperomia sp. IV		p1
Asplenium cf. linckii		p1
Acalypha volkensii		p1
Canarina eminii		p1

Table 3.76 (continued): Further species in the samples: **37_{NGa}** : Bryopsida sp. V p1; Gen. indet. spec. indet. XCI p1; Gen. indet. spec. indet. XCII p1; Primulaceae sp. r1; Cucurbitaceae sp. XV p1; **61_{NR}** : Gen. indet. spec. indet. CLXXV 5-; Rubiaceae sp. IX r1; Gen. indet. spec. indet. CLXXVII r1; Gen. indet. spec. indet. L r1; Apocynaceae sp. III r1; Cucurbitaceae sp. XVI r1

3.2.36 *Carapa grandiflora-Alangium chinense-Musanga leo-errerae* Secondary Community

UPGMA, local cut information level: 57%
Fuzzy k-means cluster number: Noise
Plots: 51_{NGs}

Locations: Nyungwe, Gasumo

Noise	3_{NU}	20_{NG}	51_{NGs}
3_{NU}	0	0.65	0.67
20_{NG}		0	0.73
51_{NGs}			0

Table 3.77: Bray-Curtis dissimilarities between the samples discussed.

Noise	3_{NU}	20_{NG}	51_{NGs}
3_{NU}	0	25.88	13.53
20_{NG}		0	36.92
51_{NGs}			0

Table 3.78: Geographic distances between the samples discused in km.

Before the vegetation of the site will be examined, a short overview of its ecological parameters will be given. The NNW facing site is positioned at the lower level of the montane rain forest found on the hills around Gasumo. The drillable soil depth and the temperature at a 0.60 m soil depth of the clay soil could not be determined. The pH reaches a value of 3.99. Four tree layers can be noticed while the canopy reaches ∼24 metres. Ground cover of both the herb and the shrub layer is below 10%.

Despite the relative closeness of the plots (i.e., 3_{NU}, 20_{NG} and 51_{NGs}), according to the UPGMA results, a clustering will not be undertaken. An overlap of three species with plot 20_{NG} does not provide sufficient reference points on which to base a classification. Plot 3_{NU} has even fewer commonalities. One species in common and the fact that the plot is firmly integrated into cluster M13 (3.2.14), constitute a major obstacle. Except for *Carapa grandiflora*, all the species that define cluster M13 are missing. Fuzzy c.means with noise clustering gives a quite different result. The sample is allocated to the noise cluster with a 87% probabilty.

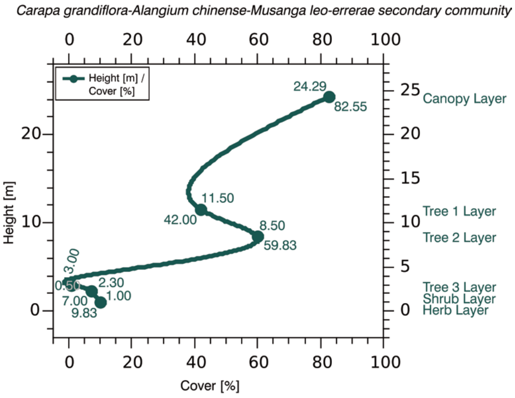


Figure 3.44: Cover-Height relation of the community recovered close to Gasumo; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Carapa grandiflora is accompanied by *Alangium chinense*, *Musanga leo-errerae* and *Maesopsis eminii*. All three species indicate secondary vegetation (for *Alangium* and *Musanga* cf. FISCHER & KILLMANN 2008; for *Maesopsis* cf. BLOESCH ET AL. 2009). While *C. grandiflora* and *A. chinense* are widespread, *Musanga leo-errerae* is an Albertine Rift endemic and a pioneer species which replaces *M. cecropioides* in the mountains of the Rift (FISCHER & KILLMANN 2008).

While *A. chinense* belongs to the Ficalhoo-Podocarpetalia (LEBRUN & GILBERT 1954) and HABIYAREMYE (1997) claims that *C. grandiflora* does too, *M. leo-errerae* has been allocated to an order and an alliance of its own by LEBRUN and GILBERT (1954). The same authors (1954) stated that *Musanga* is also a common sight within the Polyscion fulvae, an appropriation which will be followed here. The same seems to be valid for *M. eminii*. The rest of the species inventory did not simplify the classification task. In an arbitrary act, the site will be assigned to the Polyscion fulvae, mostly because of its evident secondary nature. The only option to further classify the vegetation found would be to use the *Carapa*-*Symphonia* secondary forest by FISCHER & HINKEL (1993), which is indeed not suitable to describe the species inventory at hand. Thus, a *Carapa grandiflora*-*Alangium chinense*-*Musanga leo-errerae* secondary community will be established here.

Table 3.79: *Carapa grandiflora-Alangium chinense-Musanga leo-errerae* secondary community

Sample Site / Species	3_{NU}	20_{NG}	51_{NGs}
Exposition	E	SW	NNW
Inclination [°]	0	n/a	43
Position / Relief	KS	HM	HM
Precipitation / a [mm]	1881	1581	2211
Elevation a.s.l. [m]	2501	2216	1684
T S_{60} [°C]	14	n/a	n/a
pH	2.71	3.09	3.99
Soil texture	Ut	Ts	Ts
t Height [m]	15.50	28.00	24.29
t1 Height [m]	8.00	19.00	11.50
t2 Height [m]	n/a	6.50	8.50
t3 Height [m]	n/a	n/a	3
Shrub Height [m]	3.50	2.00	2.30
Herb Height [m]	0.60	0.60	1.00
Moss Height [m]	n/a	n/a	0.06
Juvenil Height [m]	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1
Vegetation Cover [Londo]	10	10	10
t Cover [%]	84.17	148.33	82.55
t1 Cover [%]	26.67	45.67	42.00
t2 Cover [%]	0	0.25	59.83
t3 Cover [%]	0	0	0.50
Shrub Cover [%]	28.33	20.08	7.00
Herb Cover [%]	46.75	9.83	9.83
Moss Cover [%]	n/a	n/a	<1
Juvenil Cover [Londo]	4	0.7	p1
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a
Carapa grandiflora	5-	5-	8
Chassalia subochreata	2	p2	
Macaranga kilimandscharica	1.2	6	
Asplenium sandersonii	p1	p1	
Mikania cordata	p1	r1	
Oxyanthus troupinii	r1	r1	
Asplenium sp. II	p1	m1	
Symphonia globulifera		p1	r1
Dracaena laxissima		p1	r1
Syzygium parvifolium	2		
Astropanax goetzenii	2		
Mikaniopsis tedliei	1.2		
Psychotria mahonii	0.7		
Embelia libeniana	r1		
Isachne mauritiana	p1		
Rytigynia kigeziensis	p1		
Asplenium erectum	p1		
Asplenium friesiorum	p2		
Blotiella stipitata	p1		
Asplenium cf. gemmiferum	r1		
Sericanthe leonardii	r1		
Asplenium sp.	p1		
Vittaria reekmansii	p1		
Myrsine melanophloeos	r1		
Asplenium tenuicaudatum	r1		
Asplenium bugoiense	r1		

Table 3.79: *Carapa grandiflora-Alangium chinense-Musanga leo-errerae* secondary community (continued)

Sample Site / Species	3_{NU}	20_{NG}	51_{NGs}
Balthasaria schliebenii	r1		
Myrsine cf. melanophloeos	r1		
Cyperus subgen. Mariscus	r1		
cf. Asplenium sp. XXVII	r1		
Magnistipula butayei		8	
Alchornea hirtella		1.2	
Parinari excellsa		0.7	
Coleus melleri		0.7	
Sericostachys scandens		p1	
Phyllanthus nummularifolius		p1	
Mimulopsis excellens		m1	
Isoglossa vulcanicola		p1	
Strombosia scheffleri		r1	
Sanicula elata		r1	
Lasianthus kilimandscharicus		r1	
Mikaniopsis sp.		p2	
Impatiens purpureo-violacea s. l.		p1	
Pteris cf. catoptera		p1	
Rubus sp. VIII		r1	
Athyrium sp.		p2	
Alangium chinense			4
Musanga leo-errerae			4
Maesopsis eminii			3
Allophylus chaunostachys			r1
Asplenium dregeanum			m1
Shirakiopsis elliptica			r1
Microcos mildbraedii			r1
Impatiens cf. erecticornis			a2
Myrianthus holstii			r1
Piper capense			a1
Dryopteris sp. IX			r1
Pteris cf. preussii			p1
Mimulopsis arborescens			p1
Tiliacora funifera			r1
Entandrophragma excelsum			p1
Culcasia falcifolia			p1
Porotrichum variifolioides			r1
Tectaria cf. coadunata			p1
Elatostema sp.			p1
Dryopteris sp. VI			p1
cf. Dryopteris sp. XIV			p1
Allophylus abyssinicus			p1
Illigera pentaphylla			r1
Tectaria sp. IV			p1
Boehmeria virgata subsp. macrophylla			r1
Dryopteris sp. XVII			p1
cf. Begonia sp.			p1
Pteris cf. auquieri			p1
Tectaria gemmifera			p2
Antrophyum mannianum			p1
Pteris sp.			r1
Palisota mannii			p1
Didymochlaena trunculata			p4

Table 3.79: *Carapa grandiflora-Alangium chinense-Musanga leo-errerae* secondary community (continued)

Sample Site / Species	3_{NU}	20_{NG}	51_{NGs}
Celosia sp.			p1
Ampelopteris sp.			p1
Sericostachys sp. II			p1
Pseudospondias microcarpa			r1
Acanthus ueleensis			r1
Kigelia africana subsp. africana			p1
cf. Cola pierlotii			r1
Psychotria aff. peduncularis			r1
Ficus asperifolia			r1
Clausena anisata			p1
Psychotria sp. II			r1
cf. Tabernaemontana sp.			r1
Asplenium africanum			p1
Ficus sur			r1
Tabernaemontana stapfiana			r1
Marattia sp.			r1

Further species in the samples: **3_{NU}**: Polypodiales sp. III r1; **51_{NGs}**: Poaceae sp. VI p1; Gen. indet. spec. indet. CXXXVI r1; Acanthaceae sp. III p1; Gen. indet. spec. indet. CXXIX r1; Polypodiales sp. XI p1; Gen. indet. spec. indet. CXXX p1; Polypodiales sp. XIV r1; Polypodiales sp. XVII p2; Woodsiaceae sp. VII p1; Cucurbitaceae sp. VI r1; Gen. indet. spec. indet. CXXXII p1; Cucurbitaceae sp. I r1 ; Gen. indet. spec. indet. CXXXVII r1; Gen. indet. spec. indet. CXXXIV r1; Gen. indet. spec. indet. CXXXIII r1; Lilianae sp. r1

3.2.37 *Myrianthus holstii-Shirakiopsis elliptica-Carapa grandiflora* Community

Fuzzy k-means cluster number: Noise
UPGMA, local cut information level: 95%
Plot: 54_{NGs}

Locations: Nyungwe, Gasumo

Noise	54_{NGs}	62_{NR}	69_{NBw}
54_{NGs}	0	0.66	0.69
62_{NR}		0	0.97
69_{NBw}			0

Table 3.80: Bray-Curtis dissimilarities between the samples discussed.

Noise	54_{NGs}	62_{NR}	69_{NBw}
54_{NGs}	0	29.16	15.02
62_{NR}		0	27.42
69_{NBw}			0

Table 3.81: Geographic distances between the samples discused in km.

Site 62_{NR}, the most similar plot to 54_{NGs}, is neatly integrated into cluster M35, a detachment of plot 62_{NR} is not well-founded and adding plot 54_{NGs} to the cluster would be unreasonable due to every indication available. The second most likely cluster to which plot 54_{NGs} has been allotted by FCM-NC is cluster M25, which consists only of one plot–69_{NBw}. The same is also the second most similar plot to 54_{NGs}. The UPGMA dendrogram corroborates not only the decision not to merge plot 62_{NR}, which is only jointed at the 21% information level, but also supports the higher similarity to site 69_{NBw} which is jointed at the 58% Information level. Despite the similarities in species composition, both plots will remain in a cluster of their own, at least until further data is available. Reasons for this decision are, e.g., the pronounced occurrence of *M. solmsii* in plot 69_{NBw} and the absence of several tree species in the same plot.

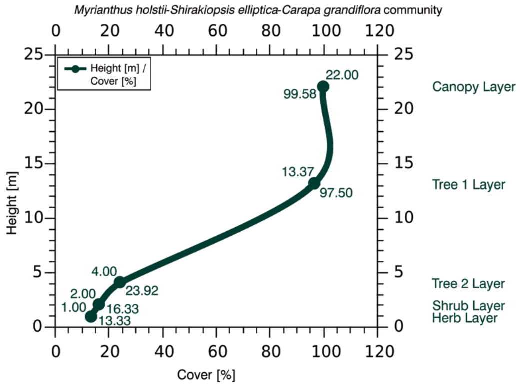


Figure 3.45: Cover-Height relation of the community recovered close to Gasumo; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

The vegetation of the sample seems to be of secondary origin. Subject to reservations, the Polyscion fulvae seems appropriate in terms of classification. Any further research did not supply a suitable vegetation unit under which the site could be subsumed. As a most preliminary solution, a *Myrianthus holstii-Shirakiopsis elliptica-Carapa grandiflora* community will be established here.

The vegetation herein is rooted in sandy soil with a drillable soil depth of 0.65 m and a pH of 3.24. The eastward facing site is situated at the lower level of the montane forest; it harbours three tree layers, the canopy of which reaches 22 metres. In the undergrowth, a shrub layer covering about 16% of the site and a herb layer with about 13% ground cover can be found.

Table 3.82: *Myrianthus holstii-Shirakiopsis elliptica-Carapa grandiflora* community

Sample Site / Species	54_{NGs}	69_{NBw}	62_{NR}
Exposition	E	WSW	n/a
Inclination [°]	28	30	n/a
Position / Relief	HM	HU	n/a
Precipitation / a [mm]	2232	1865	1655
Elevation a.s.l. [m]	1906	1915	2323
T S_{60} [°C]	n/a	16.00	15.00
pH	3.24	3.17	3.56
Soil texture	Sl	Sl	Ts
t Height [m]	22.00	20.00	11.00
t1 Height [m]	13.37	14.00	8.00
t2 Height [m]	4.00	8.00	4.00
t3 Height [m]	n/a	n/a	n/a
Shrub Height [m]	2.00	2.50	1.50
Herb Height [m]	1.00	1.00	1.00
Moss Height [m]	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1
Vegetation Cover [Londo]	10	10	10
t Cover [%]	99.58	139.08	113.33
t1 Cover [%]	97.50	0.50	55.00
t2 Cover [%]	23.92	3.42	2.33
t3 Cover [%]	0	0	0
Shrub Cover [%]	16.33	1.25	12.33
Herb Cover [%]	13.33	79.33	7.25
Moss Cover [%]	n/a	n/a	n/a
Juvenil Cover [Londo]	p1	n/a	a2
Juvenil Shrub Cover [Londo]	r1	n/a	n/a
Carapa grandiflora	3	3	p1
Clerodendrum johnstonii	1.2	p1	p1
Symphonia globulifera	r1	r1	r1
Shirakiopsis elliptica	4	3	
Strombosia scheffleri	r1	6	
Alchornea hirtella	p2	r1	
Piper capense	p1	r1	
Asplenium dregeanum	p1	r1	
Asplenium sp. IV	p1	p1	
Gouania longispicata	r1	r2	
Entandrophragma excelsum	p4	r1	
Allophylus pseudopaniculatus	p2	p1	
Tabernaemontana stapfiana	p4	r2	
Sericostachys scandens		2	p1
Polyscias fulva		1.2	p1
Begonia meyeri-johannis		p1	p1
Myrianthus holstii	7		7
Chassalia subochreata	r1		1.2
Parinari excellsa	r1		p1
Asplenium sp. VI	p1		p1
Bridelia brideliifolia	3		
Astropanax abyssinicus	1.2		
cf. Shirakiopsis elliptica	1.2		
Ficus sp. II	1.2		
Tectaria gemmifera	0.7		
Dracaena laxissima	p1		

Table 3.82: *Myrianthus holstii-Shirakiopsis elliptica-Carapa grandiflora* community (continued)

Sample Site / Species	^{54}NGs	^{69}NBw	^{62}NR
Oxyanthus speciosus	r1		
Xymalos monospora	r1		
Rourea thomsonii	r1		
Alangium chinense	r1		
Plectranthus sp.	r1		
Galiniera saxifraga	r1		
Psychotria mahonii	r1		
Asplenium aff. elliottii	p1		
Asplenium sp. XIII	p1		
Cissus oliveri	r1		
Oplismenus hirtellus	a4		
Celtis gomphophylla	r2		
Culcasia falcifolia	p1		
Antrophyum mannianum	p1		
Woodsiaceae sp. VII	p1		
Diplazium sp. IV	p2		
cf. Celosia elegantissima	p1		
Pteris aff. preussii	p2		
Asplenium sp. XXVII	p1		
Coccinia cf. mildbraedii	r1		
Peperomia sp. II	r1		
Loxogramme lanceolata	r1		
cf. Rutidea orientalis	p1		
Dalbergia lactea	r1		
Deinbollia kilimandscharica	r1		
Vittaria sp.	p1		
Lindackeria bukobensis	r1		
Ficus cf. ottonifolia	r1		
Zanthoxylum gilletii	r1		
Macaranga kilimandscharica			10
Asplenium sandersonii			p1
Embelia libeniana			p1
Ficalhoa laurifolia			p2
Salacia erecta			r1
Blotiella cf. bouxiniana			p1
Dryopteris sp. IX			a2
Diplazium sp. VI			a2
Asplenium sp. XVI			p1
Mimulopsis solmsii		5+	
Urera trinervis		p1	
Asplenium cf. friesiorum		p1	
Coccinia mildbraedii		p1	
Apodytes dimidiata		r1	
Rubus cf. apetalus		r1	
Dichanthelium cf. hillebrandianum		p1	
Mimulopsis arborescens		p2	
Celosia elegantissima		p1	
Asplenium cf. christii		r1	
Impatiens niamniamensis		p1	
Asplenium sp. XXXIII		p1	
Rubus sp. III		r1	
Aframomum cf. mala		p1	
Solanum terminale		r1	
Garcinia volkensii		r1	
Rytigynia cf. bagshawei var. lebrunii		r2	

Table 3.82 (continued): Further species in the samples: **54_{NGs}**: Acanthaceae sp. p1; Gen. nov. sp. nov. r1; Gen. indet. spec. indet. CXL r1; Gen. indet. spec. indet. CXLII p1; Gen. indet. spec. indet. CXLI r1; **69_{NBw}**: Woodsiaceae sp. I 0.7; Gen. indet. spec. indet. XXXVII r1; Poaceae sp. V p1; Gen. indet. spec. indet. XVI r1; Gen. indet. spec. indet. XXXIII r1; Gen. indet. spec. indet. XXXIV r1; Gen. indet. spec. indet. XXXV r1; Gen. indet. spec. indet. XI p1; **62_{NR}**: Gen. indet. spec. indet. CLXXVII r1

3.2.38 *Celtis gomphophylla-Microcos mildbraedii-Carapa* spec. nov. Community

Fuzzy k-means cluster number: Noise
Plot: 56_C Locations: Cyamudongo

Plot 56_C, neatly and collectively separated by UPGMA with most of the other plots in Cyamudongo, should nevertheless not be merged with any of the Cyamudongo sites. The second most similar is plot 49_C with a Bray-Curtis value of 0.89 and a joint with plot 56_C at the 16% information level by UPGMA. Site 57_C has been joined at the 41% information level and has been given a dissimilarity of 81% to site 56_C. Despite some overlap with the other sites, plot 56_C will be kept as a singleton.

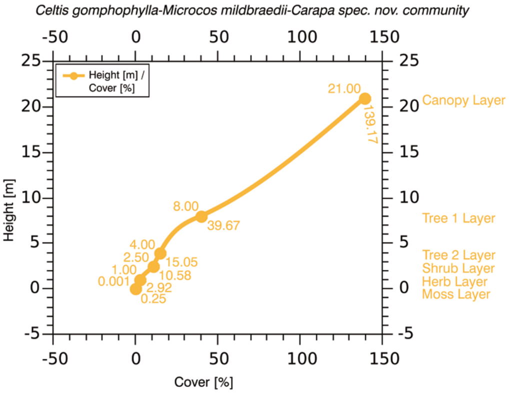


Figure 3.46: Cover-Height relation of the community recovered at Cyamudongo Forest; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

If species composition does not allow a consolidation of the sites, it can perhaps be assigned to an existing plant community. Here, relevant literature did not provide any applicable vegetation unit. Not even Fischer & Hinkel's 1993 paper on the Cyamudongo was able to provide any lead. Species composition suggests a secondary vegetation, which will be summarised using the usual provisional nature under a *Celtis gomphophylla-Microcos mildbraedii-Carapa spec. nov.* community.

The community is part of the lower-level montane cloud forest and can be found in a NNE-ward facing site with shallow sandy soils. The pH value here is 3.66, with a mean annual temperature of 17.00°C. Within the stand, three tree layers are apparent. Underneath the 21m high canopy, a shrub and herb layer can be found as well. Though the shrub layer is a bit more developed than the herb layer, both are rather sparse.

Table 3.83: *Celtis gomphophylla-Microcos mildbraedii-Carapa spec. nov.* community

Sample Site / Species	57_{C}	56_{C}	48_{C}
Exposition	NE	NNE	SE
Inclination [°]	26	10	36
Position / Relief	HM	HU/HM	MH
Precipitation / a [mm]	1639	1639	1661
Elevation a.s.l. [m]	1905	1837	1798
T S_{60} [°C]	n/a	17.00	18.25
pH	5.51	3.66	3.97
Soil texture	Ls2-3	Sl	Sl
t Height [m]	20.00	21.00	34.00
t1 Height [m]	7.00	8.00	25.79
t2 Height [m]	4.00	4.00	6.00
t3 Height [m]	n/a	n/a	4.00
Shrub Height [m]	2.30	2.50	2.50
Herb Height [m]	0.70	1.00	0.60
Moss Height [m]	n/a	0.001	0.001
Juvenil Height [m]	n/a	n/a	n/a
Epiphyts [m/6m]	0	1	1
Vegetation Cover [Londo]	10	10	10
t Cover [%]	146.33	139.17	97.58
t1 Cover [%]	75.58	39.67	26.92
t2 Cover [%]	20.78	15.05	38.67
t3 Cover [%]	0	0	4.00
Shrub Cover [%]	17.75	10.58	10.50
Herb Cover [%]	16.92	2.92	2.42
Moss Cover [%]	n/a	0.25	<1
Juvenil Cover [Londo]	2	a2	2
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a
Carapa sp. nov.	2	4	r1
Shirakiopsis elliptica	r1	r1	3
Celtis cf. gomphophylla	2	r1	p4
Culcasia falcifolia	p1	r1	r1
Newtonia buchananii	r1		r1
Xymalos monospora	p2		r1
Microcos mildbraedii		7	r1
Clerodendrum johnstonii		p2	p1
Tiliacora funifera		p2	p1
Dracaena fragrans	2	0.7	
Tectaria gemmifera	p1	p1	
Allophylus pseudopaniculatus	p1	r1	
Ficus sp. IV	9		
Croton cf. macrostachyus	4		
Polyscias fulva	p1		
Dracaena laxissima	p1		
Entandrophragma excelsum	p1		
Zanthoxylum gilletii	r1		
Asplenium cf. christii	p1		
Pteris sp. VII	r1		
Asplenium sp. XXX	p2		
Mimulopsis runssorica	p1		
Rourea thomsonii			r1
Lasianthus kilimandscharicus			r2
Pteris cf. preussii			a1

Table 3.83: *Celtis gomphophylla-Microcos mildbraedii-Carapa spec. nov.* community (continued)

Sample Site / Species	57_C	56_C	48_C
Heinsenia diervilleoides			p1
Fissidens sp.			p1
Tectaria sp. V			p2
Asplenium sp. XXVI			p1
Stephania cyanantha			r1
Strychnos lucens			r1
Lepisanthes senegalensis			r1
Oxyanthus cf. speciosus			r1
Pancovia sp.			p1
Drypetes sp.			r1
Tabernaemontana odoratissima			p1
Ehretia sp.			r1
Cola pierlotii			r2
Celtis durandii		7	
cf. Celtis gomphophylla		0.7	
Pleiocarpa pycnantha		p2	
Lindackeria bukobensis		p1	
Astropanax abyssinicus		r1	
Porotrichum elongatum		p1	
Clerodendrum buchananii		r1	
Asplenium sp. XXIX		r1	
Antrophyum cf. mannianum		r1	
cf. Saba comorensis		r1	
Loeseneriella africana		p2	

Further species in the samples: **57_C**: Gen. indet. spec. indet. CLIV r1; Gen. indet. spec. indet. LXV p4; Gen. indet. spec. indet. XXXVII 6; Acanthaceae sp. V r1; Gen. indet. spec. indet. CLXVIII r1; Gen. indet. spec. indet. XII r1; Gen. indet. spec. indet. CLXVII r1; Gen. indet. spec. indet. CLXIV r1; Gen. indet. spec. indet. XLIII r1; Gen. indet. spec. indet. CLXVI r1; Gen. indet. spec. indet. XLII r1; Gen. indet. spec. indet. XLIV r1; **56_C**: Gen. indet. spec. indet. CLIV p1; Gen. indet. spec. indet. LXV p1; Gen. indet. spec. indet. XXXIX 0.7; Gen. indet. spec. indet. CLIII p1; Poaceae sp. p1; Gen. indet. spec. indet. CLVIII r1; Gen. indet. spec. indet. CLX r1; Gen. indet. spec. indet. CLV r1; Acanthaceae sp. IV m1; Loranthaceae sp. r1; Gen. indet. spec. indet. CLVII r1; Gen. indet. spec. indet. CLVI r2; Meliaceae sp. r1; Gen. indet. spec. indet. CLIX r1; **48_C**: Gen. indet. spec. indet. LXXII 7; Gen. indet. spec. indet. CXIX 3; Gen. indet. spec. indet. LXXIII 1.2; Gen. indet. spec. indet. LXXI 1; Poaceae sp. VI p1; Acanthaceae sp. II p1; Gen. indet. spec. indet. CXII r1; Rubiaceae sp. VII r1; Gen. indet. spec. indet. CXXII r1; Gen. indet. spec. indet. CXXIII r1; Gen. indet. spec. indet. LXXIV r1; Gen. indet. spec. indet. LXXV p2; Gen. indet. spec. indet. LXXVI r1; Gen. indet. spec. indet. LXXVII r4; Gen. indet. spec. indet. LX p1; Gen. indet. spec. indet. CXXI r1

3.2.39 *Ficus* sp. IV - *Croton* cf. *macrostachyus* Community

Fuzzy k-means cluster number: Noise
Plot: 57_C Locations: Cyamudongo

The plot at hand has already been briefly reviewed in the preceding paragraph. Further similarities have been found in plot 48_C and, due to FCM-NC secondary cluster probability, in plots 58_C and 59_C. For all three sites dissimilarity exceeds 90%; therefore, the sites will not be clustered. There are very few indications of a correspondence to the *Newtonia-Parinari* secondary forest of Fischer & Hinkel (1993). Overall, the incomplete identification of most of the formative species does not allow for the assignment to or the establishment of a vegetation unit. In order to address the vegetation unit during further analyses, it will be entitled as *Ficus sp.* IV-*Croton cf. macrostachyus* community.

This site faces to the NE and can be found at the lower level of the montane cloud forest. The shallow loam soil did not permit measurement of the temperature at a 0.60 m soil depth. The pH value is 5.51. The community consists of three tree layers with a canopy reaching 20 m in height. Both, the shrub and the herb layer cover about 17% of the site.

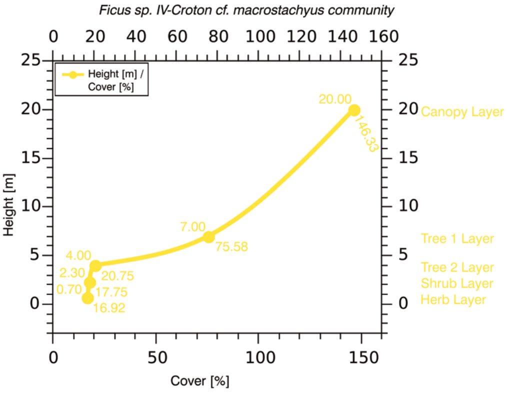


Figure 3.47: Cover-Height relation of the community recovered at Cyamudongo Forest; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Table 3.84: *Ficus* sp. IV-*Croton* cf. *macrostachyus* community

Sample Site / Species	48_C	56_C	57_C	58_C	59_C
Exposition	SE	NNE	NE	SW	N
Inclination [°]	36	10	26	42	40
Position / Relief	MH	HU/HM	HM	HM	HO
Precipitation / a [mm]	1661	1639	1639	1623	1623
Elevation a.s.l. [m]	1798	1837	1905	2005	2018
T S_{60} [°C]	18.25	17.00	n/a	16<16.5	17.00
pH	3.97	3.66	5.51	3.39	3.04
Soil texture	Sl	Sl	Ls2-3	Sl	Ts
t Height [m]	34.00	21.00	20.00	31.86	23.45
t1 Height [m]	25.79	8.00	7.00	11.00	n/a
t2 Height [m]	6.00	4.00	4.00	6.00	6.50
t3 Height [m]	4.00	n/a	n/a	n/a	n/a
Shrub Height [m]	2.50	2.50	2.30	2.00	2.50
Herb Height [m]	0.60	1.00	0.70	0.50	0.50
Moss Height [m]	0.001	0.001	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	0	1	0
Vegetation Cover [Londo]	10	10	10	10	10
t Cover [%]	97.58	139.17	146.33	90.58	58.00
t1 Cover [%]	26.92	39.67	75.58	93.83	61.75
t2 Cover [%]	38.67	15.05	20.78	47.58	30.67
t3 Cover [%]	4.00	0	0	0	0
Shrub Cover [%]	10.50	10.58	17.75	6.50	6.67
Herb Cover [%]	2.42	2.92	16.92	13.50	13.83
Moss Cover [%]	<1	0.25	n/a	n/a	n/a
Juvenil Cover [Londo]	2	a2	2	0.7	a2
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	n/a	p2
Carapa sp. nov.	r1	4	2	p4	p4
Culcasia falcifolia	r1	r1	p1	r1	
Xymalos monospora	r1		p2	2	1.2
Shirakiopsis elliptica	3	r1	r1		
Celtis cf. gomphophylla	p4	r1	2		
Clerodendrum johnstonii	p1	p2		p2	
Tectaria gemmifera		p1	p1	a2	
Newtonia buchananii	r1		r1		
Microcos mildbraedii	r1	7			
Tiliacora funifera	p1	p2			
Dracaena fragrans		0.7	2		
Allophylus pseudopaniculatus		r1	p1		
Polyscias fulva			p1	r1	
Entandrophragma excelsum			p1	r2	
Astropanax abyssinicus		r1		p1	
Symphonia globulifera				5	7
Myrianthus holstii				4	p2
Chassalia subochreata				p4	r1
Asplenium sp. IV				a2	a4
Albizia gummifera				r1	r2
Senegalia montigena				p1	p4
Asplenium sp. XXXI				p1	p1
Peperomia sp. III				p1	p2
Diplazium sp. VII				p1	0.7
cf. Diplazium sp.				p1	p1
Ficus sp. IV			9		

Table 3.84: *Ficus* sp. IV-*Croton* cf. *macrostachyus* community (continued)

Sample Site / Species	48C	56C	57C	58C	59C
Croton cf. macrostachyus			4		
Dracaena laxissima			p1		
Zanthoxylum gilletii			r1		
Asplenium cf. christii			p1		
Pteris sp. VII			r1		
Asplenium sp. XXX			p2		
Mimulopsis runssorica			p1		
Rourea thomsonii	r1				
Lasianthus kilimandscharicus	r2				
Pteris cf. preussii	a1				
Heinsenia diervilleoides	p1				
Fissidens sp.	p1				
Tectaria sp. V	p2				
Asplenium sp. XXVI	p1				
Stephania cyanantha	r1				
Strychnos lucens	r1				
Lepisanthes senegalensis	r1				
Oxyanthus cf. speciosus	r1				
Pancovia sp.	p1				
Drypetes sp.	r1				
Tabernaemontana odoratissima	p1				
Ehretia sp.	r1				
Cola pierlotii	r2				
Celtis durandii		7			
cf. Celtis gomphophylla		0.7			
Pleiocarpa pycnantha		p2			
Lindackeria bukobensis		p1			
Porotrichum elongatum		p1			
Clerodendrum buchananii		r1			
Asplenium sp. XXIX		r1			
Antrophyum cf. mannianum		r1			
cf. Saba comorensis		r1			
Loeseneriella africana		p2			
Oxyanthus speciosus				5-	
Tabernaemontana stapfiana				3	
Alangium chinense				2	
Tabernaemontana cf. stapfiana				1.2	
Piper capense				r1	
Asplenium sp. VI				p1	
Macaranga kilimandscharica				r1	
Sericostachys scandens				r1	
Oxyanthus troupinii				r1	
Elatostema monticola				p1	
Keetia sp. I				r1	
Asplenium cf. sandersonii				p1	
Adenia sp.				p1	
Drypetes gerrardii				r1	
Dalbergia lactea				r1	
Loxogramme abyssinica				r1	
Dryopteris sp. XVIII				a4	
Pteris cf. pteridioides				a1	
Asplenium sp. XII				r1	
Asplenium sp. XVIII				p1	

Table 3.84: *Ficus* sp. IV-*Croton* cf. *macrostachyus* community (continued)

Sample Site / Species	48_C	56_C	57_C	58_C	59_C
Strychnos sp.				r1	
Agelaea pentagyna					4
Oxyanthus cf. troupinii					2
Gambeya gorungosana					0.7
Parinari excellsa					r1
Psychotria peduncularis					r1
Polypodiales sp. XXII					p1
Peddiea fischeri					r1
Asplenium sandersonii					p1
Dryopteris sp. XII					p1

Further species in the samples: **48_C**: Gen. indet. spec. indet. LXXII 7; Gen. indet. spec. indet. CXIX 3; Gen. indet. spec. indet. LXXIII 1.2; Gen. indet. spec. indet. LXXI 1; Poaceae sp. VI p1; Acanthaceae sp. II p1; Gen. indet. spec. indet. CXII r1; Rubiaceae sp. VII r1; Gen. indet. spec. indet. CXXII r1; Gen. indet. spec. indet. CXXIII r1; Gen. indet. spec. indet. LXXIV r1; Gen. indet. spec. indet. LXXV p2; Gen. indet. spec. indet. LXXVI r1; Gen. indet. spec. indet. LXXVII r4; Gen. indet. spec. indet. LX p1; Gen. indet. spec. indet. CXXI r1; Gen. indet. spec. indet. XXXIX 0.7; **56_C**: Gen. indet. spec. indet. CLIV p1; Gen. indet. spec. indet. LXV p1; Gen. indet. spec. indet. CLIII p1; Poaceae sp. p1; Gen. indet. spec. indet. CLVIII r1; Gen. indet. spec. indet. CLX r1; Gen. indet. spec. indet. CLV r1; Acanthaceae sp. IV m1; Loranthaceae sp. r1; Gen. indet. spec. indet. CLVII r1; Gen. indet. spec. indet. CLVI r2; Meliaceae sp. r1; Gen. indet. spec. indet. CLIX r1; **57_C**: Gen. indet. spec. indet. CLIV r1; Gen. indet. spec. indet. LXV p4; Gen. indet. spec. indet. CLXIV r1; Gen. indet. spec. indet. XXXVII 6; Acanthaceae sp. V r1; Gen. indet. spec. indet. CLXVIII r1; Gen. indet. spec. indet. XII r1; Gen. indet. spec. indet. CLXVII r1; Gen. indet. spec. indet. XLIII r1; Gen. indet. spec. indet. CLXVI r1; Gen. indet. spec. indet. XLII r1; Gen. indet. spec. indet. XLIV r1; **58_C**: Gen. indet. spec. indet. CLXIV r1; Araceae sp. p1; Gen. indet. spec. indet. CLXIX p1; Gen. indet. spec. indet. CLXX r1; Gen. indet. spec. indet. CLXXI r1; Gen. indet. spec. indet. CLXXII r1; Gen. indet. spec. indet. XLV r2; Fabaceae sp. p1; **59_C**: Araceae sp. p1; Gen. indet. spec. indet. CLXXIII r1; Gen. indet. spec. indet. CLXXIV r2; Gen. indet. spec. indet. LXVI r1

3.2.40 *Mimulopsis arborescens-Alangium chinense* Secondary Community

Fuzzy k-means cluster number: Noise

Plot: 60_C Locations: Cyamudongo

Located at Cyamudongo Forest, this plot is separated by UPGMA at the 2% information level. This isolated position is substantiated by the results of FCM-NC and the Bray-Curtis values. The secondary cluster to which the site has been allocated is M29. Although consisting of Cyamudongo-plots, species composition and Bray-Curtis values with an average of 0.93 to M29 do not allow for unification. The two most similar plots 51_{NGs} and 47_C with respective dissimilarities of 84% and 87% are not to be merged either.

As with most of the plots that have been set aside into the noise cluster, site 60_C cannot be assigned to an existing vegetation unit. The not entirely closed canopy holds a mixture of species which do not facilitate classification. Neither does the fact that half the species could not be identified. The herb layer instead consists almost exclusively of *Mimulopsis arborescens*, giving very little hint of a possible syntaxonomic unit. Species composition only reveals a secondary character. Thus, another interim solution is constructed–a *Mimulopsis arborescens*-*Alangium chinense* secondary community.

Not only does the herb layer consist of an almost pure stand of *M. arborescens*, it is exceedingly dense as well. The two-metre-high shrub layer on the other hand is barely existent. Two tree layers are visible, the canopy of which reaches 20 m in height. The exposition of the plot is NNW at the lower level of the montane cloud forest. The sandy soil has a drillable soil depth of 0.95 m and a pH of 5.40 and the mean annual temperature is 18.00°C.

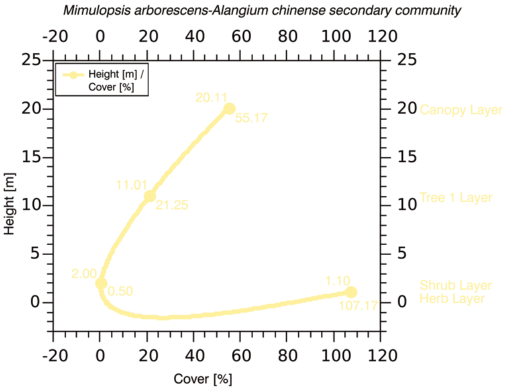


Figure 3.48: Cover-Height relation of the community recovered at Cyamudongo Forest; values below the points indicate ground cover in %, Values above the points indicate stratum height; subfix numbers are minimum values, superior numbers are maximum values.

Table 3.85: *Mimulopsis arborescens-Alangium chinense* secondary community

Sample Site / Species	47_{C}	51_{NGs}	58_{C}	59_{C}	60_{C}
Exposition	SSE	NNW	SW	N	NNW
Inclination [°]	12	43	42	40	28
Position / Relief	KH	HM	HM	HO	HM
Precipitation / a [mm]	1649	2211	1623	1623	1639
Elevation a.s.l. [m]	2041	1684	2005	2018	1876
T S_{60} [°C]	15.90	n/a	16<16.5	17.00	18.00
pH	4.20	3.99	3.39	3.04	5.40
Soil texture	Ls4	Ts	Sl	Ts	Sl
t Height [m]	53.69	24.29	31.86	23.45	20.11
t1 Height [m]	8.00	11.50	11.00	n/a	11.01
t2 Height [m]	4.50	8.50	6.00	6.50	n/a
t3 Height [m]	n/a	3.00	n/a	n/a	n/a
Shrub Height [m]	3.00	2.30	2.00	2.50	2.00
Herb Height [m]	1.00	1.00	0.50	0.50	1.10
Moss Height [m]	n/a	0.06	n/a	n/a	n/a
Juvenil Height [m]	n/a	n/a	n/a	n/a	n/a
Epiphyts [m/6m]	1	1	1	0	1
Vegetation Cover [Londo]	10	10	10	10	10
t Cover [%]	79.42	82.55	90.58	58.00	55.17
t1 Cover [%]	86.25	42.00	93.83	61.75	21.25
t2 Cover [%]	6.50	59.83	47.58	30.67	0
t3 Cover [%]	0	0.50	0	0	0
Shrub Cover [%]	8.58	7.00	6.50	6.67	0
Herb Cover [%]	15.42	9.83	13.50	13.83	107.17
Moss Cover [%]	0	<1	n/a	n/a	n/a
Juvenil Cover [Londo]	0.7	p1	0.7	a2	n/a
Juvenil Shrub Cover [Londo]	n/a	n/a	n/a	p2	n/a
Alangium chinense	2	4	2		2
Symphonia globulifera	1.2	r1	5	7	
Myrianthus holstii	p2	r1	4	p2	
Xymalos monospora	p4		2	1.2	
Chassalia subochreata	p4		p4	r1	
Carapa sp. nov.	0.7		p4	p4	
Asplenium sp. IV	p1		a2	a4	
Tectaria gemmifera		p2	a2		p1
Piper capense		a1	r1		r1
Albizia gummifera			r1	r2	0.7
Entandrophragma excelsum	p4	p1	r2		
Parinari excellsa	3			r1	
Psychotria peduncularis	0.7			r1	
Polyscias fulva	r1		r1		
Clerodendrum johnstonii	p1		p2		

Table 3.85: *Mimulopsis arborescens-Alangium chinense* secondary community (continued)

Sample Site / Species	47_C	51_{NGs}	58_C	59_C	60_C
Asplenium sp. VI	r1		p1		
Shirakiopsis elliptica	1.2	r1			
Asplenium dregeanum	p1	m1			
Dracaena laxissima	p1	r1			
Pteris cf. preussii	a2	p1			
Tiliacora funifera	r1	r1			
Mimulopsis arborescens		p1			10
Gouania longispicata	r1				p2
Senegalia montigena			p1	p4	
Asplenium sp. XXXI			p1	p1	
Peperomia sp. III			p1	p2	
Diplazium sp. VII			p1	0.7	
cf. Diplazium sp.			p1	p1	
Tabernaemontana stapfiana		r1	3		
Culcasia falcifolia		p1	r1		
Newtonia buchananii	5+				
Strombosia scheffleri	1.2				
Zanthoxylum cf. mildbraedii	0.7				
Dalbergia cf. lactea	0.7				
Lasianthus kilimandscharicus	r1				
Cassipourea ndando	r1				
Asplenium erectum	a2				
Asplenium aff. elliottii	p1				
Dryopteris sp. XVI	a2				
Asplenium sp. XXV	p1				
Adenia sp. I	r1				
Cissus oliveri	p1				
Brachystephanus sp.	r1				
Celosia elegantissima	p1				
Culcasia scandens	p1				
cf. Piper sp.	p1				
Asplenium sp. XXIII	r1				
Scadoxus multiflorus	r1				
Toddalia asiatica	r1				
Ekebergia capensis	r1				
cf. Ancylobothrys sp.	r1				
Heinsenia diervilleoides	r2				
Celtis gomphophylla	p1				
Elaeodendron sp.	r2				
Hylodesmum repandum	p1				
Carapa grandiflora		8			
Musanga leo-errerae		4			

Table 3.85: *Mimulopsis arborescens-Alangium chinense* secondary community (continued)

Sample Site / Species	47C	51NGs	58C	59C	60C
Maesopsis eminii		3			
Impatiens cf. erecticornis		a2			
Allophylus chaunostachys		r1			
Dryopteris sp. IX		r1			
Marattia sp.		r1			
Microcos mildbraedii		r1			
Porotrichum variifolioides		r1			
Tectaria cf. coadunata		p1			
Elatostema sp.		p1			
Dryopteris sp. VI		p1			
cf. Dryopteris sp. XIV		p1			
Allophylus abyssinicus		p1			
Illigera pentaphylla		r1			
Tectaria sp. IV		p1			
Boehmeria virgata subsp. macrophylla		r1			
Dryopteris sp. XVII		p1			
cf. Begonia sp.		p1			
Pteris cf. auquieri		p1			
Antrophyum mannianum		p1			
Pteris sp.		r1			
Palisota mannii		p1			
Didymochlaena trunculata		p4			
Celosia sp.		p1			
Ampelopteris sp.		p1			
Sericostachys sp. II		p1			
Pseudospondias microcarpa		r1			
Acanthus ueleensis		r1			
Kigelia africana subsp. africana		p1			
cf. Cola pierlotii		r1			
Psychotria aff. peduncularis		r1			
Ficus asperifolia		r1			
Clausena anisata		p1			
Psychotria sp. II		r1			
cf. Tabernaemontana sp.		r1			
Asplenium africanum		p1			
Ficus sur		r1			
Oxyanthus speciosus			5-		
Tabernaemontana cf. stapfiana			1.2		
Macaranga kilimandscharica			r1		
Sericostachys scandens			r1		
Oxyanthus troupinii			r1		
Elatostema monticola			p1		

Table 3.85: *Mimulopsis arborescens-Alangium chinense* secondary community (continued)

Sample Site / Species	47_{C}	51_{NGs}	58_{C}	59_{C}	60_{C}
Keetia sp. I			r1		
Asplenium cf. sandersonii			p1		
Adenia sp.			p1		
Drypetes gerrardii			r1		
Dalbergia lactea			r1		
Astropanax abyssinicus			p1		
Loxogramme abyssinica			r1		
Dryopteris sp. XVIII			a4		
Pteris cf. pteridioides			a1		
Asplenium sp. XII			r1		
Asplenium sp. XVIII			p1		
Strychnos sp.			r1		
Agelaea pentagyna				4	
Oxyanthus cf. troupinii				2	
Gambeya gorungosana				0.7	
Peddiea fischeri				r1	
Asplenium sandersonii				p1	
Dryopteris sp. XII				p1	
Ficus sp. VI					3
Acalypha sp.					0.7
Acalypha ornata					m2
Pavonia sp.					a1
Keetia sp.					r1
Solanum terminale					r1
Gymnosporia heterophylla					r1
Dombeya torrida					r1
Cucumis sp.					p1
Maesa lanceolata					r2

Further species in the samples: **47_{C}**: Poaceae sp. VI p1; Gen. indet. spec. indet. CXI p1; Gen. indet. spec. indet. CXIV r1; Gen. indet. spec. indet. CXIII r1; Gen. indet. spec. indet. CXV r1; Gen. indet. spec. indet. LXXXVIII r2; Gen. indet. spec. indet. XXVIII r1; Gen. indet. spec. indet. XXIX r1; **51_{C}**: Poaceae sp. VI p1; Gen. indet. spec. indet. CXXXVI r1; Acanthaceae sp. III p1; Gen. indet. spec. indet. CXXIX r1; Polypodiales sp. XI p1; Lianae sp. r1; Gen. indet. spec. indet. CXXX p1; Polypodiales sp. XIV r1; Polypodiales sp. XVII p2; Woodsiaceae sp. VII p1; Cucurbitaceae sp. VI r1; Gen. indet. spec. indet. CXXXII p1; Cucurbitaceae sp. I r1; Gen. indet. spec. indet. CXXXVII r1; Gen. indet. spec. indet. CXXXIV r1; Gen. indet. spec. indet. CXXXIII r1; **58_{C}**: Araceae sp. p1; Gen. indet. spec. indet. CLXIV r1; Gen. indet. spec. indet. CLXIX p1; Gen. indet. spec. indet. CLXX r1; Gen. indet. spec. indet. CLXXI r1; Gen. indet. spec. indet. CLXXII r1; Gen. indet. spec. indet. XLV r2; Fabaceae sp. p1; **59_{C}**: Araceae sp. p1; Polypodiales sp. XXII p1; Gen. indet. spec. indet. CLXXIII r1; Gen. indet. spec. indet. CLXXIV r2; Gen. indet. spec. indet. LXVI r1; **60_{C}**: Gen. indet. spec. indet. LXVII 1.2; Cucurbitaceae sp. V r1; Rubiaceae sp. VIII p1; Gen. indet. spec. indet. XLIX r1

3.3 Global Cut of the UPGMA Dendrogram

Since in the last paragraph the pruning of the dendrogram was undertaken in an unorthodox way, we will now have a look at what a global cut would reveal. In an educated attempt, the dendrogram was pruned at the 45% information level. The number of communities has been reduced, resulting in both a reduction of data and loss of detail. The plant communities thus established are quite heterogenous, showing the scarce overlap often found at higher syntaxonomic levels.

It is not to be said that the supra-communities established here will not be dissolved, renamed or expanded. For now, they only represent the status quo found during the survey and consequently represent the characteristics of the Rwandan montane rain forests. In particular, the large number of singletons has to be revised in light of more comprehensive data.

3.3.1 *Dombeya torrida-Maesa lanceolata-Acalypha ornata* Community

Plots: 85_{Gw}, 86_{Gw}, 89_{Gw}, 93_{Gw}, 81_{Gw}

Right at the beginning, the limitation of the global cut has to be disregarded. The circumstance that plot 81_{Gw} is close to a natural interior edge and, hence, probably represents a fringe community has already been explained under point 3.2.1. Species combination and the reasoning as to the establishment of the community can be taken from the same paragraph and the corresponding table. Already visible in the dendrogram stemming from UPGMA, the community is clearly separated with a possible join only at the ~9.5% information level. The FCM-$\mathrm{NC}_{\mathrm{RC}}$ that was undertaken based on of the Raup-Crick dissimilarity resulted in a corresponding clear-cut cluster with negligible successive memberships.

3.3.2 *Maesa lanceolata-Arthropteris monocarpa-Macaranga kilimandscharica* Community

Plots: 66_{NBw}, 67_{NBw}, 68_{NBw}

Another community which is set apart quite clearly is the one established from plots around Bweyeye. A link to the other communities described can only be established at the ~14% information level. Plot 87_{Gw} could be added a little earlier at the 37.5% information level. The decision to keep the community as a singleton is supported by the clear results stemming from FCM-$\mathrm{NC}_{\mathrm{RC}}$.

3.3.3 *Dombeya rotundifolia-Polyscias-Acanthaceae* sp. XII Community

Plots: 87_{Gw}

As mentioned in the preceding paragraph, the site in Gishwati Forest could only be joined at the 37.5% information level of the UPGMA dendrogram and accordingly remains a singleton until further data is available. The finding is bolstered by the corresponding clear outcome of the FCM-$\mathrm{NC}_{\mathrm{RC}}$ clustering.

3.3.4 *Podocarpus latifolius-Isoglossa vulcanicola* Supra-Community

Plots: 26_{NB}, 29_{NB}, 31_{NB}, 27_{NB}, 24_{NB}, 25_{NB}, 28_{NB}, 22_{NB}, 23_{NB}, 30_{NB}

Within this supra-community, almost all sites on Mt. Bigugu are joined. The characteristic species here is *Podocarpus latifolius*. Despite the differing abundance, the species is present in all plots. *Isoglossa vulcanicola* appears in all but two sites. Though its abundance is quite low, the species has been accommodated into the denomination as it seems to be a characteristic of higher altitudes. At least in this study, the species has only occurred once outside Bigugu at Gisovu. Troupin (1985) described the species as occurring in montane forests but only in the range of 2100-2730 m a.s.l. which, in the given study, is exceeded in many cases and – as mentioned – the species has been found only once outside Bigugu. Troupin (ibid.) depicted a variation occurring in Rwanda, i.e., *I. vulcanicola* var. *vulcanicola*, but he did not specify if the species demonstrates a different distribution pattern. As frequent as *I. vulcanicola Myrsine melanophloeos* is occurring more often in places other than Mt. Bigugu and there in even lower abundances. Therefore, a description bearing the name of the species is not indicated at this point. The same is true for all other species to an even greater extent. Consolidation of the three communities is aided by a sufficient species overlap and the reciprocal memberships of the plots revealed by FCM-NC. In other words, the numerical method points to a certain degree of kinship between the *Podocarpus-Erica mannii-Asplenium friesiorum* community *(Erica mannii* dominated ecotonal community) and the *Podocarpus latifolius-Isoglossa vulcanicola-Pilea rivularis* community as well as the *Podocarpus latifolius-Myrsine-Mimulopsis excellens-Isoglossa vulcanicola* community. Morphology, hindering the clustering process in the first place, should be neglected at this point by virtue of the higher order of the established supra-community. Including the ecotonal communities, this supra-community represents the marked species composition of the higher forest zones at Mt. Bigugu in Nyungwe National Park, Rwanda.

3.3.5 *Syzygium parvifolium* Supra-Community

Plots: 1_{NU}, 6_{NU}, 7_{NU}, 41_{NK}, 63_{NR}, 2_{NU}, 4_{NU}, 8_{NU}, 79_{NGk}, 76_{NGk}, 77_{NGk}, 80_{NGk}

Despite the elevated dissimilarity values, species overlap–especially of the most abundant species–is sufficient to establish this supra-community. Abundance patterns are of particular relevance since the high differences of up to 44 species between the respective species count per plot lead to a great variety of species overlap. The results stemming from FCM-NC can be consulted in support of the UPGMA global cut. Though most of the plots have a given secondary membership to the noise cluster, all of them have a tertiary, quaternary or quinary membership to the other clusters combined here. The fuzzy clustering with noise based on the Raup-Crick dissimilarity undertaken to find a partition that can accommodate the supra-communities yields inconclusive results. The *Beilschmiedia* community and the *Syzygium-Macaranga* community form a cluster of their own. The *Syzygium-Alchornea* community is joined in a cluster with the Macarangao-Psychotrietum dominated, communities are comprised as well. The *Syzygium-Symphonia* community is included in the noise cluster. Since the Raup-Crick index is based on occurrence data only, the FCM-NC$_{RC}$ results have to be taken with a grain of salt (v.i.). Consequently, species patterns within the plots supersede in the origination of the present supra-community. This supra-community is then named after the most prominent member *Syzygium parvifolium*. Although *Chassalia subochreata* occurs in every plot as well, its inclusion into the community's identifier seems questionable. The species is present in half the surveyed plots, and the abundances within the sites constituting the supra-community at hand do not give rise to its possible consideration as a characteristic species. *Alchornea hirtella*, although only occurring in just more than half the plots considered here, seems to have its highest abundances within the communities belonging to the *Syzygium parvifolium* dominated units. On the other hand, *A. hirtella* is widespread (FISCHER & KILLMANN, 2008) and, therefore, equally ineligible as an adjunct in this supra-community's name. The possibility of using *A. hirtella* within the limits of this work has already been satisfied through the logic of WILMANNS (1998, p.36) in paragraph 3.2.2. It is also necessary to consider the more comprehensive framework of the higher syntaxonomical unit. Here, the probability of including further communities in the event of ameliorated data availability should also be considered. *Macaranga kilimandscharica* occurs in more than half the plots. Of these plots, only site 63_{NR}, which is spatially close to plot 65_{NR}, has a heightened similarity to the *Macaranga* dominated communities. It has been included here due to the reasons given in the pertinent chapter (3.2.34, p. 160). As a reminder, the decision was not taken lightly and was based on the assumption that there might be a transition between the two communities. For plot 41_{NK}, the higher similarities are only with two *Macaranga* dominated sites and, thus, do not leave room for excessive deliberations. Species compositions and abundances can be taken from Table 3.6 (p. 57).

3.3.6 Standard Tree Secondary Supra-Community

Plots: 49_C, 50_C

An overlap in species inventory of ∼40% makes the combination of these two plots possible. Additionally, the most abundant species in each plot are not exponents of any known plant community. As collateral, according to FCM-NC, both plots have a subordinated membership in the other respective cluster. Further information and Species composition / configuration can be found in table 3.7 (p. 59). Provided the future data is compelling, the denomination should be changed to *Elaeodendron buchananii* dominated community.

3.3.7 *Hagenia abyssinica* Supra-Community

Plots: 18_{NG}, 35_{NGa}, 36_{NGa}

All of the plots belong to the noise cluster as a secondary membership as has been detected by FCM-NC. Furthermore, the 3° and 4° memberships are with the other cluster, respectively. The FCM-NC_{RC} analysis separates both clusters. The observations below explain why the combination of the *Hagenia* secondary community with the *Podocarpus* dominated communites by FCM-NC_{RC} is not too surprising. Morphologically highly diverse and with a separate species overlap which just allows for unification, the three sites are situated within the medium-level of montane forest bordering on the higher level. This location puts them right within the possible zone for a *Hagenia-Hypericum* belt as illustrated by FISCHER & KILLMANN (2008). However, such a belt seems to be typical only for the Virunga-Volcanos (IBID., see also FISCHER, 1996). While plots 18_{NG} and 35_{NGa} show quite a number of similarities with the *Podocarpus* dominated communities, plot 36_{NGa} exhibits more similarities with the *E. mannii* dominated stands at the upper levels of the montane forests. Yet again, the RAUP-CRICK index is incidence based and, therefore, false conclusions are likely to be drawn. Although the number of shared species would suggest that a combination is possible, the abundances and dissimilarity values weigh against it. Communities similar to the *H. abys-*

sinica-E. mannii-L. clavatum community (36_{NGa}) have been described by Fischer & Hinkel (1993) to occur within the Nyungwe Forest at corresponding habitats. Communities comparable to the stand in plot 35_{NGa} have been characterised by Fischer as *Macaranga neomildbraediana* secondary forest for the Kahuzi-Biega NP. These also bear some resemblance to the vegetation in plot 18_{NG}. Due to the abundances and species compositions, both plots are circumscribed better by the denomination chosen in the work at hand; this also applies to the *Hagenia abyssinica* secondary forest described within the same work (Fischer, 1996). The stands in Nyungwe Forest exhibit some similarities but must not be lumped together with their counterparts in the Kahuzi-Biega NP. Lebrun & Gilbert (1954) characterised forests containing *H. abyssinica* as secondary. This assessment seems to be true for the stands at hand as well. However, species combination still does not allow for a classification in the Hagenietum abyssinicae. In conclusion, a *Hagenia abyssinica* supra-community will be established on a preliminary basis.

3.3.8 *Erica mannii* Dominated Supra-Community

Plots: 17_{NG} , 14_{NG}, 15_{NG}, 19_{NG}, 78_{NGk}

The exiguous data availability leaves this syntaxonomic unit with only one namesake. *Erica mannii* is prominent in all of the plots; where the abundance is low the canopy cover is low as well. Although only occurring in little more than half the plots, *Aristida adoensis* seems to have its main appearance in this community. Inclusion of the species into the name of the supra-community is arguable and it has been avoided. The mutual memberships found by FCM-NC assist in the formation of this supra-community; however, species overlap characterises these communities as very heterogenic. Yielded by FCM-NC_{RC}, the communties are alloted into seperated clusters while the *Erica-Microlepia-Breutelia* edaphic community was placed in the noise cluster. Though joined on a higher level in the dendrogram, the community will be incorporated here due to species overlap and the Bray-Curtis values. Tertiary membership to a cluster formed by the *Hagenia-Erica-Lycopodium* community should only be discussed in light of a more stable data basis. The combination of the Ericetum and the *Erica-Faurea-Aristida* community is still an option since the secondary and tertiary memberships are reciprocal. The *Erica* ecotone, which might be expected in the cluster at hand, is set in the noise cluster and will be discussed in the pertinent paragraph.

The communities comprised here occur largely on northern expositions on sandy, shallow ground where rooting depth is limited mostly by solid rock. The edaphic community of plot 78_{NGk} offers an illustrative example. With a 2004 m a.s.l., this site is also the only one outside the 2575-2772m a.s.l. altitudinal zone which spans right across the transition from mid to upper-level montane forest (Fischer & Killmann, 2008) and, therefore, adds to the significance of the edaphic factor. (Site 78_{NGk} is found surrounded by *Syzygium* dominated communities.) The communities are of low canopy height which does not exceed 9 m and which can get as low as 2.5 m. If more than one tree stratum occurs, no more than two can be found.

According to Habiyaremye (1997), the Ericetum johnstonii belongs to the order Oleo-Jasminetalia. Within this order, the "*alliance montagnarde*" Agaurio-Myricion (Lebrun & Gilbert, 1954, p. 71) can comprise all of the plots at hand, i.e., the supra-community. As a thought, the establishment of a sub-alliance representing the Rwandan variety of the sclerophyll vegetation – with a tendency towards lauriforme or ericoide–(see Lebrun & Gilbert, 1954.) may be envisaged.

3.3.9 *Macaranga kilimandscharica* Supra-Community

Plots: 34_{NGa}, 82_{Gw}, 90_{Gw}, 46_{NK}, 38_{NGa}, 39_{NGa}, 40_{NGa}, 42_{NK}, 45_{NK}, 9_{NU}, 11_{NU}, 32_{NB}, 62_{NR}, 64_{NR}, 65_{NR}, 71_{NM}, 72_{NM}, 73_{NM}, 74_{NM}, 94_{Gw}, 33_{NGa}, 43_{NK}, 44_{NK}, 70_{NM}, 75_{NM}, 83_{Gw}, 91_{Gw}, 61_{NR}, 37_{NGa}

When it comes to numerical methods, the support for this supra-community is mainly based on the consecutive memberships of the plots yielded by FCM-NC; these are, for the most part, complementary. Cluster M30, which has already been resolved and integrated into the Macarango-Psychotrietum under 3.2.34 (p. 160) and the *Macaranga* dominated secondary community (3.2.28, p. 136), is an illustrative example. Reciprocity then is reflected by species overlap and the respective Bray-Curtis values. At this point, the singleton 20_{NG} serves as a further example. If the combination with the other plots was a problem in the corresponding paragraph (3.2.15, p. 96), the circumstances that are also apparent from the discussion under point 3.2.15 are more prominent here. The *Magnistipula butayei*-*Macaranga kilimandscharica*-*Carapa grandiflora* community has sufficient intersections to be combined with the other vegetation units.

The fuzzy noise clustering based on the Raup-Crick index displays the limitations of incidence-based dissimilarity indices. The communities subsumed under the *Macaranga* supra-community are spread over several clusters. Three of the communities form a cluster which they share with the *Psychotria*-*Maesa*-*Xymalos* community. Since the similarities between sample 71_{NM} and 16_{NG} have already been discussed this does not come as a surprise. Two of the communities form a cluster of their own respectively. The *Macaranga* dominated community from Gishwati forest has been placed in the noise cluster. The *Magnistipula*-*Macaranga*-*Carapa* community shares a cluster with *Carapa* dominated communities. Thus, the results stemming from FCM-$\mathrm{NC}_{\mathrm{RC}}$ will only be consulted as a pointer.

The vast majority of the plots subsumed under this supra-community label share *M. kilimandscharica* which, in most samples, is the predominant species within the canopy stratum. The core of the distribution is to be found within the Macarango-Psychotrietum and the *Macaranga*-*Chassalia subochreata*-*Mimulopsis excellens* community. The second most common species is *Chassalia subochreata* although it only rarely can be observed in higher abundance. The same is valid to an even higher degree for *Begonia meyeri-johannis* and *Sericostachys scandens*, the third and fourth most frequent species.

Mostly three tree layers are present. Within the single communities *Macaranga* reaches heights from 9 to above 29 m. Shrub cover varies between very low abundance to elevated medium coverage. At the same time, the herb layer shows no particular trend and ranges from almost non-existent to very dense. The altitudinal distribution spans a somewhat narrow belt of 430 m between 2115 and 2545 m a.s.l. Exposition does not show any preference, and nearly all soil textures are occurring. The mean annual temperatures range between 13°C and 16°C.

3.3.10 *Psychotria mahonii-Maesa lanceolata-Xymalos monospora* Supra-Community

Plot: 16_{NG}

This supra-community is yet another singleton which, even on an elevated level of dissimilarity, could not be joined with another community without effort. Here a join might be possible at the 36% information level to the plots on Mt. Bigugu. An information surplus, i.e., a stable community, cannot be achieved this way since the average dissimilarity would be beyond 70%. The FCM-NC_{RC} derived clustering sets the community into one cluster with most of the sites dominated by *M. kilimandscharica*. At this point, species overlap and the Bray-Curtis values preclude a combination. For details see: 3.2.20 (Tab. 3.45, p. 112).

3.3.11 *Carapa grandiflora* Dominated Supra-Community

Plots: 21_{NG}, 51_{NGs}

One of the most heterogeneous clusters derived by a global cut is the *Carapa grandiflora* dominated supra-community. Generally speaking, the formation of communities is rife with arbitrariness and tentativeness, and this supra-community is no exception. The reasons for plot 51_{NGs} remaining a singleton have been discussed under 3.2.36. Yet, for the sake of a wider focus of the syntaxonomical unit established here, plot 21_{NG} will be joined. As discussed, earlier plot 51_{NGs} and 21_{NG} have seven species in common. Overlapping of the species rich plot 51_{NGs} is generally low. In accordance, the Bray-Curtis dissimilarities are generally high, starting from 68% and upwards. Since none of the species abundant in plot 51_{NGs} are of a formative character for any plant community described in the literature so far, species overlap with plot 21_{NG} shall be sufficient to establish this supra-community. In light of a more extensive data basis, both samples will probably be joint with different vegetation units. Here, the integration of plot 21_{NG} into the *Macaranga* dominated sites should be taken into consideration. In this respect, the primary membership derived by FCM-NC_{RC} to a cluster also comprising the *Magnistipula-Macaranga-Carapa* community already gives a hint. Plot 51_{NGs} is set into the noise cluster.

The mostly fine textured soil of the plots is quite shallow in both cases. *Carapa grandiflora* dominates the canopy layer in plot 51_{NGs} and shares prevalence with *P. fulva* in plot 21_{NG}. Both canopies reach a height of about 25 m. The shared species *S. globulifera*, *D. laxissima*, *A. chaunostachys*, *A. chinense*, *M. holstii* and *P. capense* are only present in minute abundances. Plot 51_{NGs} belongs to the lower-level montane forest, while plot 21_{NG} belongs to the medium level. In both cases the soil was too shallow to measure the temperature. Expositions of the plots are almost diametrical.

3.3.12 *Triumfetta cordifolia-Brillantaisia nitens* Supra-Community

Plots: 10_{NU}

One of the true outliers is given its own supra-community. The most similar site has a Bray-Curtis dissimilarity index of 0.95, FCM-NC_{RC} sets the site into the noise cluster while species overlap to other sites and communities is negligible. Most certainly, more similar sites could be found on an ameliorated data basis. However, since every open community sampled is dissimilar to a great extent a higher diversity–as might be supposed within the open habitats–can be expected, nevertheless. For details see: 3.2.17 (Tab. 3.36, p. 101).

3.3.13 *Parinari excelsa-Ocotea usambarensis-Chassalia subochreata* Supra-Community

Plots: 5_{NU}, 12_{NU}, 13_{NU}, 53_{NGs}

These plots are remaining as the community found and described under 3.2.21. At the 30% information level of the UPGMA tree, a rather heterogenous community could be established comprising the (supra-)community described in paragraph 3.3.5. The presence of *S. parvifolium* and a few additional species triggered the 3° membership of the community at hand to a similar cluster formed by FCM-NC_{RC}. However, the primary membership computed by FCM-NC_{RC} results in a cluster consisting only of the given community.

The exposition of the plots ranges from WNW to ENE with the exception of site 53_{NGs} which faces SE-ward. The drillable soil depth is between 0.63 m and 0.92 m, just in the medium range of the surveyed sites. In the case of plot 53_{NGs}, it is just not deep enough to determine the soil temperature. In the other cases, the mean annual temperature reaches 15°C for plots 12_{NU} and 13_{NU} and 13.50°C for plot 5_{NU}. The pH values of the mostly sandy soils are bound between 2.95 and 2.47. Except for plot 53_{NGs}, which is settled just at the upper border of the lower-level montane forest, all the other plots are settled within the medium-level. With one exception, three tree layers can be distinguished, and the canopy reaches heights between 20 and 29 m.

3.3.14 *Shirakiopsis elliptica* Supra-Community

Plots: 48_{C}

The *Shirakiopsis elliptica* supra-community represents yet another singleton originating from Cyamudongo Forest. This site, however, demonstrates only very few similarities to the other plots in the forest; the dissimilarities here range between 80% and 100%. The most similar plot in Nyungwe Forest around the ranger station in Gasumo is dissimilar to 77%. The FCM-NC_{RC} based on the Raup-Crick dissimilarity sets the community apart as a singleton as well. Thus, until further data is available, the vegetation stand found at the site remains the only proponent of its kind. The vegetation and site are described under 3.2.22 (Tab. 3.49, p. 118).

3.3.15 *Symphonia-Myrianthus* Supra-Community

Plots: 92_{Gw}, 58_{C}, 59_{C}, 84_{Gw}, 88_{Gw}

Species overlap and Bray-Curtis dissimilarities just permit a combination of the plots at hand. The aggregation of the plots is supported by the clearly distinguished branch within the dendrogram stemming from UPGMA. When it comes to FCM-NC_{RC}, the results are rather mixed. The *Symphonia* community is set aside in a cluster of its own, while the *Xymalos* community has been set in a rather heterogenous cluster. Certainly, the overlap some species leaves room for debate. In the end, it is species abundance and the well-known limits of incidence-based data that dictate the formation of the supra-community described in this paragraph.

Except for plot 58_{C}, which is facing north, all plots have an exposition between S and SW. The temperature range is between 14.50°C and 17°C, while the pH ranges between 3.04 and 3.82. The drillable soil depth does not exceed 1.13 m and can get as shallow as 0.36 m. The sites located at Cyamudongo Forest belong to the lower-level and the rest of the sites to the medium-level of the montane rain forest. The lowest canopy can be found in one of the Gishwati plots at 13 m. In general, the canopy height ranges between 23 and 31 m. All of the plots harbour three tree strata.

3.3.16 *Newtonia-Parinari* Supra-Community

Plots: 47_C, 55_C

Fairly different, yet species overlap seems to be sufficient to establish this community at the given pruning level. Both plots are not jointed with others until the 31% information level in the UPGMA dendrogram, thus ameliorating the quite long distance between both sites themselves. Although the clustering undertaken on the basis of the Raup-Crick index joins both communities in one cluster, the resulting unit is quite heterogenous. A combination with the other communities cannot be undertaken for reasons of species combinations and abundances. Species overlap among plots 47_C and 55_C seems appealing, abundances and vegetation structure are however not well represented by the incidence-based data. In conclusion, the vegetation structure in conjunction with the Bray-Curtis values and UPGMA result, permit the establishment of this supra-community (see 3.2.26, Tab. 3.55, p. 132).

Soil pH of the shallow soils reaches 4.00 to 4.20. In plot 47_C, the mean annual temperature reaches 15.90°C. In the other plot the soil was too shallow to measure the temperature. Soil texture is loam with a low sand percentage. The exposition of the plots shows no preference. Both sites can be found in the lower level of the montane rain forest and harbour three tree strata. While within plot 55_C the canopy reaches a height of 11 m and in plot 47_C 53 m are reached.

3.3.17 *Carapa grandiflora-Strombosia scheffleri* Supra-Community

Plots: 52_{NGs}, 69_{NBw}, 54_{NGs}

About 17 km apart, two sites at Gasumo and one site at Bweyeye constitute a supra-community which is a conglomerate of sites that were either cast into the noise by FCM-NC or constitute a cluster on their own. Species overlap is highly variable, and the Bray-Curtis indices leave room for doubt. In light of a more profound data basis, the plots might be joined with other communities. For now, the result given by UPGMA and the species overlap hold the basis for this supra-community, which is held together by *C. grandiflora* and *S. scheffleri*.

The exposition of the sites varies between E via SE to WSW with a mean annual temperature between 16 and 17.7°C. Soil depth reaches 1.27 m and gets as shallow as 0.64 m. The mostly sandy soils have pH values between 2.95 and 3.24. All of the plots are situated at the lower level of the montane rain forest. The vegetation shows three tree layers between 20 and 22 m of canopy height.

3.3.18 *Celtis gomphophylla-Microcos mildbraedii-Carapa* spec. nov. Supra-Community

Plots: 56_C

As with the following community, this vegetation stand remains a singleton. Its highest similarity with plot 57_C is about 20%; therefore, neither species overlap nor abundance allows for a combination of the two. Most of the higher-level memberships found by FCM-NC are with communities consisting of plots from Cyamudongo or at least containing a site surveyed there. Yet, a fusion is not appropriate. Resulting from FCM-NC$_{RC}$, sample 56$_C$ is set into the noise cluster.

3.3.19 *Ficus* sp. IV-*Croton* cf. *macrostachyus* Supra-Community

Plots: 57$_C$

The rationale for this supra-community has been discussed above. The same arguments apply. The result stemming from FCM-NC$_{RC}$ must be refused on the basis of insufficient species overlap.

3.3.20 *Mimulopsis arborescens*-*Alangium chinense* supra-community

Plot: 60$_C$

As with the other singletons in this section, this supra-community has been established mostly for the sake of the headline. The minute subsequent memberships emanating from FCM-NC give little hint of possible commonalities, which is not too surprising since the most similar plot has a percentage dissimilarity of 84%. The FCM-NC$_{RC}$ clustering undertaken using the Raup-Crick dissimilarity, sets the community as a single cluster apart with consecutive memberships not sufficient to establish another community.

3.3.21 Summary of the Classification Section

Most of the clusters that resulted from each of the two approaches showed reasonable agreement between the both approaches. The fact that many of the samples remained as singletons is not only an expression of natural conditions and high diversity, but also a sign of undersampling. Apart from this, it is striking that the number of clusters obtained via FCM-NC corresponds to the numbers equivalent (equally likely samples) obtained as a measure of β-diversity according to Jost (2007) when one sets $q = 0$. The singletons that emerge from the noise cluster are of course excluded here. It should also be noted that the samples with a particularly high contribution to the LCBD as shown under point 3.1 (p. 46) also remained as singletons after classifications. At this point, it is noteworthy that the majority of these samples are from Cyamudongo Forest, which showed only few similarities with the other forests throughout the analysis. To what extent a further consolidation of the communities, as was done under 3.3, is useful depends on the goal of the respective future survey. However, the use of incidence-based indices quickly reaches its limits at this point. Although it could be shown that some of the results can be fitted into the existing Braun-Blanquet-based phytosociological system, whether this is possible on a regular basis can only be clarified on an expanded data basis. Overall, it could be shown that patterns in the species composition can be detected with numerical methods even with small sample sizes. How and whether these patterns can be related to environmental variables will be examined in more detail in the following chapters.

4 Ordination Results

In the previous section, clustering techniques have been applied uncoupled from environmental factors to determine whether or not species composition in the samples alone could be used to find recurring patterns and, thus, compile species communities. The results of the cluster analyses fully reveal the validity of RAMENSKY'S words (1930, p. 330; 2.6). With this, we turn to the ordination of the independent variables and attempt to show their arrangement within their own natural continuum. This continuum is determined by abiotic and biotic factors and is, in its persistence, empirically tangible. In the following we shall elucidate how the independent variables may impact the continuities and if the further reduction of subjectivities and independent variables leads to the detection of underlying environmental gradients visible in the display of the continuum.

4.1 Unconstrained Ordination

First, an unconstrained ordination was conducted to project the relationships between species in multidimensional space into a space with a reduced number of dimensions. Here, a configuration was sought that minimised distortions of the spatial relationships (see ŠMILAUER & LEPŠ,). Two methods with different properties were employed to find the ordination axes that best predict the species configuration, and thus the differences in their species composition.

4.1.1 Polar Ordination

In order to take a first look at the data in terms of underlying environmental gradients, a much moot technique was applied. The merits of the Polar Ordination method or BRAY-CURTIS ordination (1957) will be used here as an introduction to the multivariate analyses section. In the analyses, first, the original method was used to test if the outliers as described in sections 3.1 and 3.3.21 are visible also in an ordination. In the next step, a cursory overview was obtained to test if the most quoted and evident environmental parameters are the most prominent among the environmental factors recorded on site. The categorical variables have been tested for their effects and used as grouping variables. The quantifiable environmental variables have been evaluated in terms of their impact as well. Only the factors which are of explanatory value to the variation extracted by the axes will be discussed in the following. As with all analyses, all species only occurring once have been removed prior, leaving the species number at 382 in the 94 sites surveyed. As a distance measure, the BRAY-CURTIS distance has been utilised.

As has been stated, the original method forces the points with the largest distances to the endpoints of the respective axis, and this then gives, as in other methods as well, a somewhat biased ordination and does not help with plot interpretation. On the other hand, outliers are readily visible. As can be seen from graph 4.1, the four sites which have been segregated by both clustering techniques employed are conspicuous here as well. It is unsurprising that among the outliers are plot 10_{NU} and plot 60_{C}. The endpoints of the first axis are then sites 10_{NU} and 94_{Gw}. In an informed decision, only site 10_{NU} will be given the status of an outlier. Axis two has the endpoints of site 60_{C} and site 50_{C}, which is somewhat surprising since it suggests that the dissimilarity between the two plots from Cyamudongo Forest is so high as to make two opposite poles. Though the graphs vary little between the different projection methods, the amount of variation explained by both does (City Block Projection not shown). While the projection based on the Euclidean distance represents a cumulative variation of 15.11%, the city block measure extracted 56.19% of the variation on the first five axes under the specifications of the original method used by Bray & Curtis (1957). Thus, the extracted variation is kept quite low due to the overbearing impact of the largest distances.

The variation represented through the axes has been minimally increased by removing plots 10_{NU}, 49_{C}, 50_{C} and 60_{C}. The relation of the environmental variables elevation, temperature, precipitation and distance from the forest margin to the axes in terms of the linear portion has been slightly increased, and with the distance from the forest margin, the fraction represented by a single axis has been increased, i.e., the division among the axes has been lowered. The correlations of [Al], [C]:[N], pH, μS decreased after removing the outliers (All results not shown). In comparison with the environmental matrix, the four plots do not present values for these variables that would in any way represent highly divergent values in the context of the complete sample. Since removing samples from the survey also causes a loss of information, the sites shall remain in the sample of the parent population. Despite the acceptance of a slightly more cumbersome interpretation, we will see if these will cause further distortions as we progress. When it is deemed appropriate, an indication will be given.

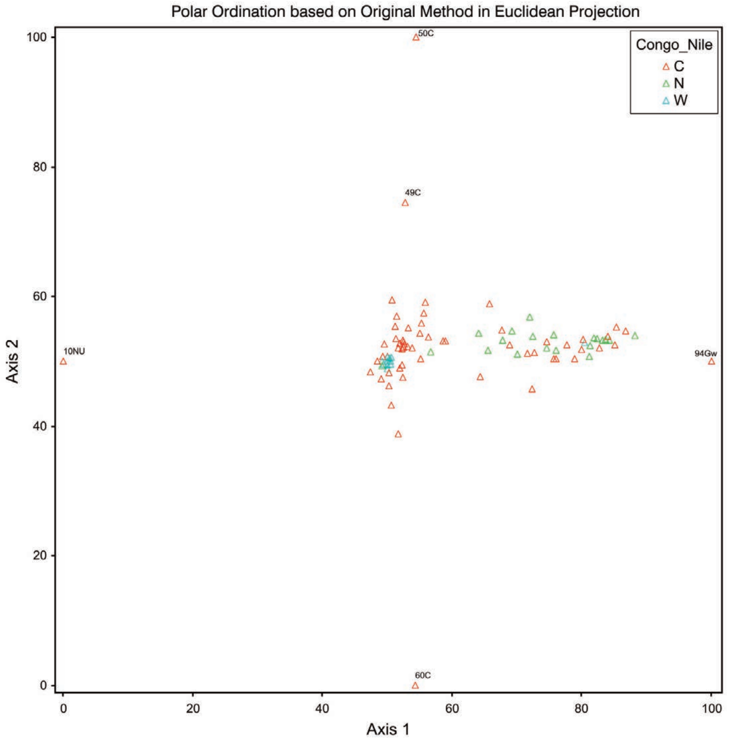


Figure 4.1: Illustrative result of a Polar Ordination as available in PC-Ord. Only axes 1 and 2 are shown. The outliers are clearly visible at the respective ends of the respective axes.

Nevertheless, an overview of the species having an impact on the positioning of the sites along the axis will be given here. Taken from a species overlay on the graph (not shown), for site 10_{NU} *Mikania sp.*, *Coleus maculosus ssp. edulis*, *Impatiens sp.* and *Triumfetta cordifolia* seem to be the species causing the main difference to the other plots. *Cassipourea ruwenzoriensis* and *Momordica foetida* as well as *Crassocephalum montuosum* add to the dissimilarity. For site 60_{C}, the copious abundance of *Mimulopsis arborescens* is the main factor for the distance of the site to the others. The presence of *Acalypha sp.* does little to increase this gap. Site 49_{C} and site 50_{C} share a couple of species, among them are *Elaeodendron* cf. *buchananii*, *Coffea eugenioides*, *Vepris nobilis*, *Acanthaceae sp.* and *Poaceae* sp. IV. Site 50_{C} is set further apart by the species: *Ritchiea albersii*, *Casearia runssorica* and *Rinorea angusitfolia*. It is to be found out to which environmental factor the higher abundance of these species is tied. Species patterns will be discussed further at the end of the section concerned with ordination.

Using the variance regression method for endpoint selection proposed by Beals (1984), it is apparent from Figure 4.2 that the outlier effect is no longer present. From the graph, however, another issue common to unimodal response data along a gradient becomes apparent; the formation of an arch, or better, of a horseshoe. This matter is ameliorated by the city block projection method as used in Figure 4.3. The sample sites made as outliers by the original method are now integrated into the bulk of the sample sites (not shown). The results show an extracted variation of 33.16% of the original matrix on the first axis. While the second axis extracted 15.82 % and the third 15.22%, which gives an accumulated 64.20% of the original distance matrix. Since the information represented by the higher axes may contain spurious effects and interpretation is rather volatile, only the first three axes will be evaluated. The fit between the distances in species space and the distances in ordination space is given in Table 4.1.

	R Squared	
Axis	Increment	Cumulative
1	0.068	0.068
2	0.026	0.094
3	0.007	0.1

Axis pair	r	Orthogonality, % = 100(1-r^2)
1 vs 2	0.119	98.6
1 vs 3	0.201	95.9
2 vs 3	0.337	88.7

Table 4.1: Left: Coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space
Right: Increment and cumulative R-squared were adjusted for any lack of orthogonality of axes.

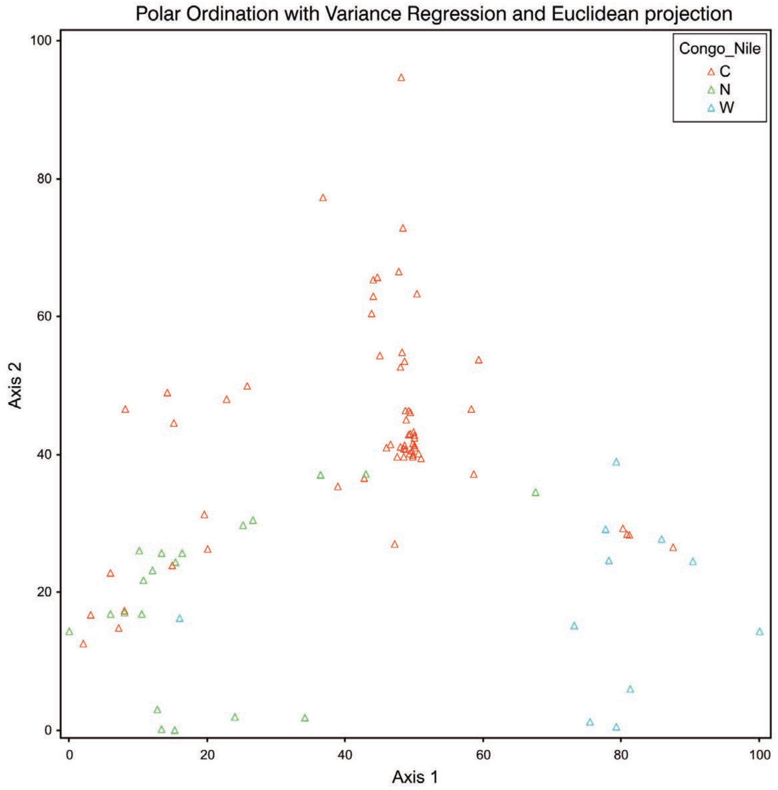


Figure 4.2: Illustrative example of a Polar Ordination as available in PC-Ord. Only axes 1 and 2 are shown. The outliers are no longer readily discernible. Instead, a horseshoe with strong involutions at the ends is depicted.

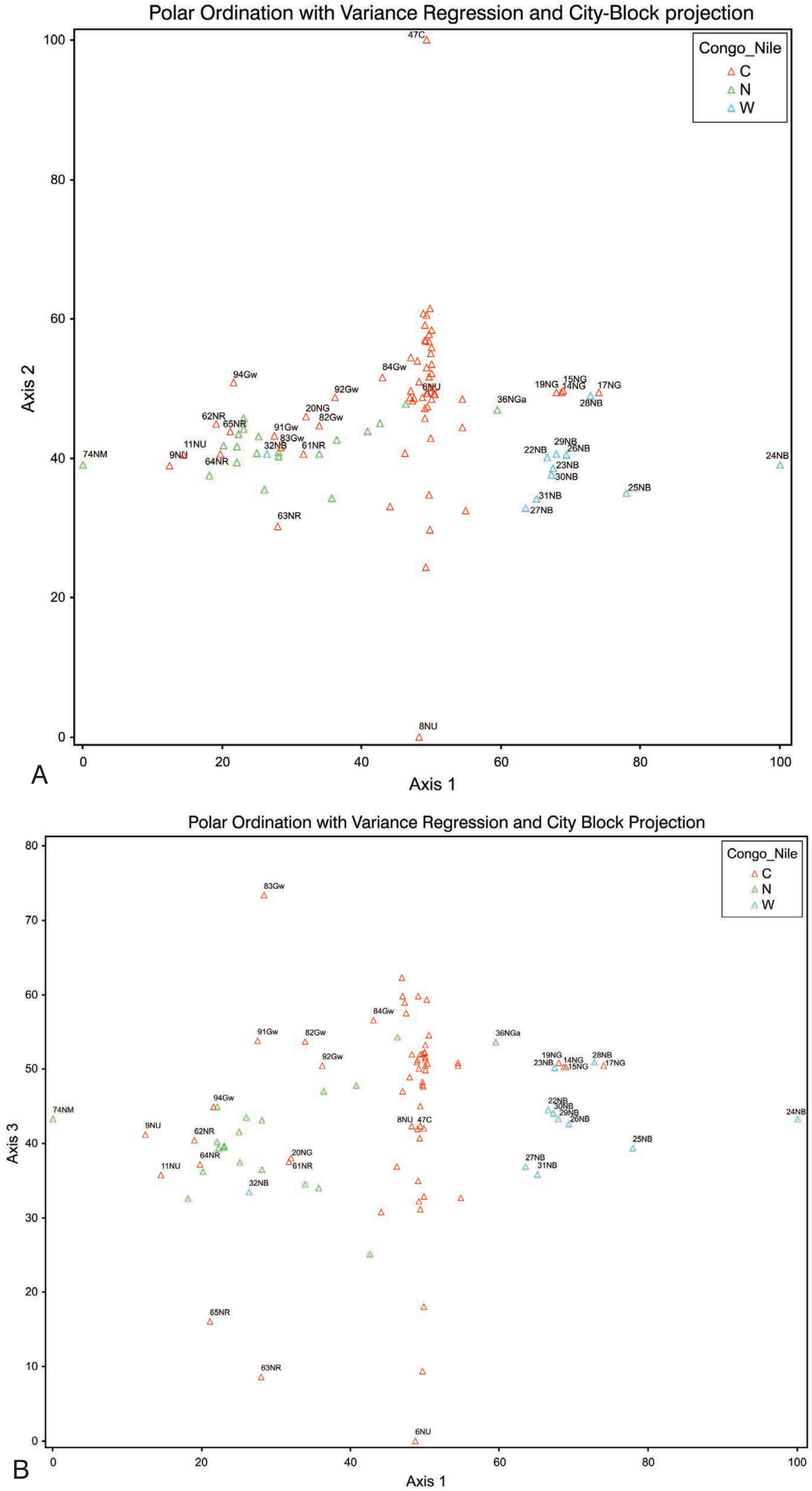


Figure 4.3: A (upper pane) Plot of axis one and axis two derived from a Polar Ordination. The separation of the samples from the different positions on the watershed is readily visible. An increased variance of the endpoints of axis two could be inferred. Axes one and three are depicted in B (lower pane).

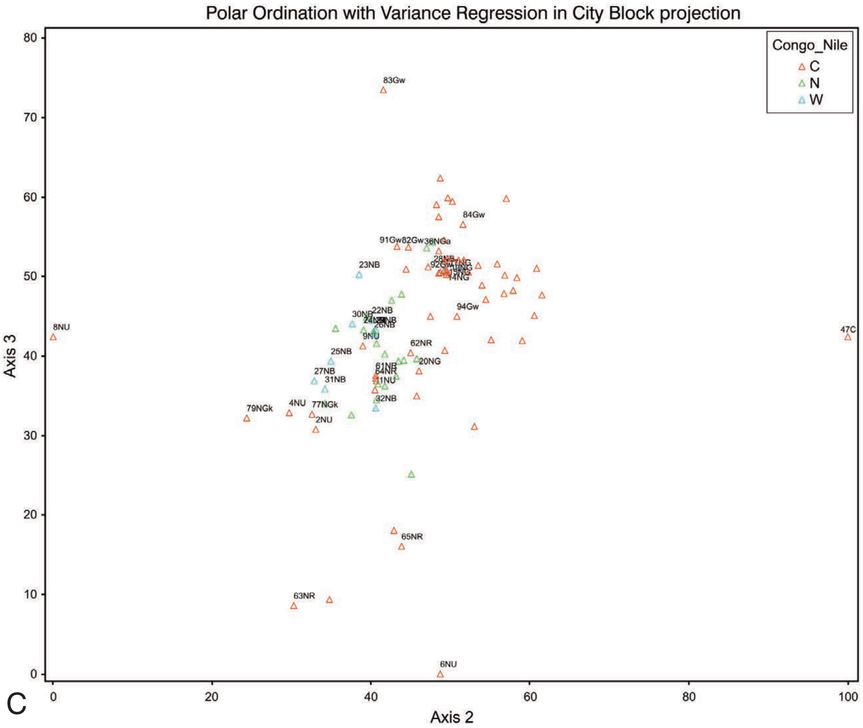


Figure 4.3: C Depiction of axes two and three. The watershed-related separation is still apparent. The spatial relations of the samples appear to be distorted by the impact of the endpoints of axis two.

What is also apparent, though, is the separation of the sites along the first and second axes. Choosing the location in reference to the watershed as the grouping variable, it is apparent that there is some kind of gradient between the respective sites of the watershed. Within this figure, the site symbols have been colour-coded in terms of their geographical position in relation to the watershed dividing Nyungwe Forest. The sites depicted by red triangles are situated in the western part and water runs off towards the Congo River. For the green triangles, the sites represented here drain towards the Nile River. Since the sites on Mt. Bigugu are situated directly on the watershed itself, they have been marked with W and given a light blue colour. As can be seen from the graph, the sites are positioned together on axis one except for site 32_{NB}, which is positioned at some distance from the other plots among sites which are mostly drained into the River Nile. This outcome might be due to the fact that the sample was positioned on the foot of the mountain; thus, elevation has had less of an impact. That the sample was also positioned on the middle of a hillside just west, i.e., on the Congo side of the watershed, might add to its similarity with the other sites. For Gishwati Forest, the situation is even less apparent. Of the 14 sites surveyed in Gishwati Forest, six have been separated by the ordination along axis one and are seemingly quite similar to stands located east of the watershed. The same is the case with the five sites sampled near the ranger station at Ruzizi. The effect is ameliorated on axis two and vanishes for the samples from Gishwati Forest almost entirely on axis three. To a lesser extent, the same is true for two sites around Uwinka. On axis one, sites 9_{NU} and 11_{NU} are well separated. Along axis two, only site 8_{NU} is positioned further apart. It seems that with axis one, the main dissimilarity gradient of the samples from the Nile side of the watershed has been extracted. With axes two and three, the main gradient between the sites at Uwinka seems to have been extracted. The dissimilarities between the samples from the Congo side seem to be generally best represented by the second and third axes, although axis one still contains some information.

When plotting axes one and two against each other, the notion arises that the samples on the Congo side are somewhat more similar to each other than the samples on the Nile side. The scatter plot of axis two against axis three changes this impression, and the samples on Mt. Bigugu are brought closer to the samples on the Nile side and to some of the samples close to Uwinka. Which, if any, of the surveyed environmental factors may impact the floristic distinctness of the vegetation of the samples?

While the grouping variable is kept, it can be read from Figure 4.4 that a relationship between precipitation per year and the Congo side of the watershed, i.e., the sampling sites there, might be inferred, as the size of the triangles shows the magnitude of the impact variable. While the r^2 values of 0.09 and 0.007 to axes one and two do not point to a strong correlation, at least not for the linear part, a clearly unimodal response can be read from both axes; although, the shape is much less pronounced on axis one. The correlation to axis three is low, as well and the unimodal response can also be inferred. For both axes (two and three) the mode is in the mid-range of the axis with an insignificant tendency towards the lower left sector for the sites with higher precipitation. From the plot of axes one and three, it can be seen that precipitation is somewhat higher on the Congo side and that the samples set aside from Gishwati Forest receive lower annual precipitation. Since all of the samples from Gishwati show the same phenomena, the separation along axis one is still inexplicable. Samples 9_{NU} and 11_{NU} seem to be separated on this axis due to some other cause as well, which appears also to be the case for the sites at Ruzizi, although precipitation is slightly lower for the samples from Ruzizi.

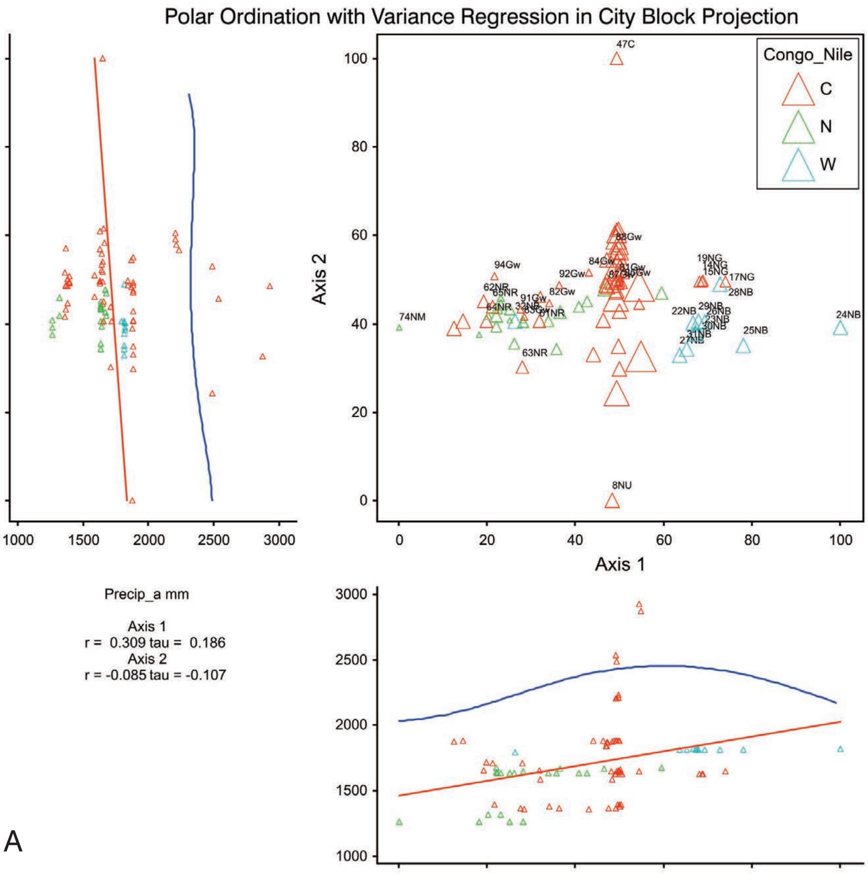


Fig. 4.4: Polar Ordination of the sites with the position in respect to the watershed as a grouping variable. Site symbols are colour-coded (red triangles for drainage into the Congo River, green for the River Nile, light blue for a position directly on the watershed, i.e., Mt Bigugu). Mean annual precipitation has been used as an overlay, the symbol size indicates the magnitude of the variable. The scatterplots on the site/below show the individual relationship of the variable with the respective axis. The linear fraction represented by both axes is negligible, but both axes exhibit a unimodal response of the species integrated by the sample sites, i.e., their ordination in sample space. While the one for axis two is more pronounced.

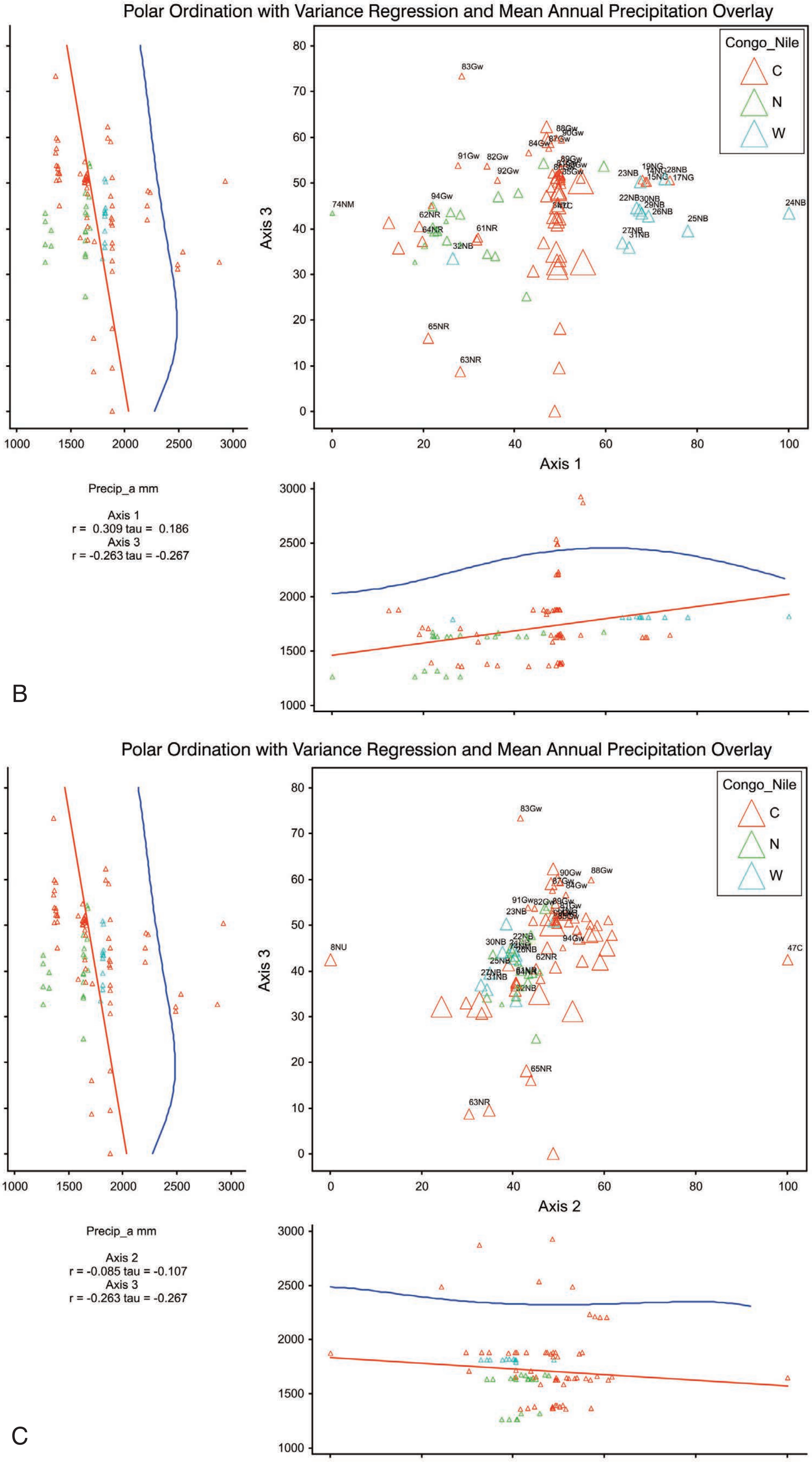


Figure 4.4: pane B and pane C
See above for description.

The next figure (4.5) highlights the possible relation between the elevation and ordination of the sites. Again, the correlation coefficients do not point to a strong linear relation, and the unimodal responses are more or less apparent. Although somewhat obscured, it can be seen from a plot of axes two and three that the altitude on the Congo side is, on average, slightly lower than on the Nile side. This finding is illustrated by the sequence of red via green to light blue triangles from the upper right to the lower left around the centre of the plot. From the plot of axis one against axis two, the proximity of the sites on Mt. Muzimu (samples 14_{NG} to 19_{NG}) to the samples on Mt. Bigugu can be seen, and elevation might play a significant part here. However, site 16_{NG}, which is placed at the summit region of Mt. Muzimu, is slightly separated, and elevation might not be solely at work. Axis two shows a minor negative linear trend with the lowest elevations on the far end of the axis. Most of the sites in Cyamudongo Forest and from around Gasumo are to be found here. Nevertheless, the linear correlation is weak, and as can be seen from the position of samples 77_{NGk} and 79_{NGk} at Gisakura, elevation cannot be the sole reason for the separation from the samples at the other end of the axis.

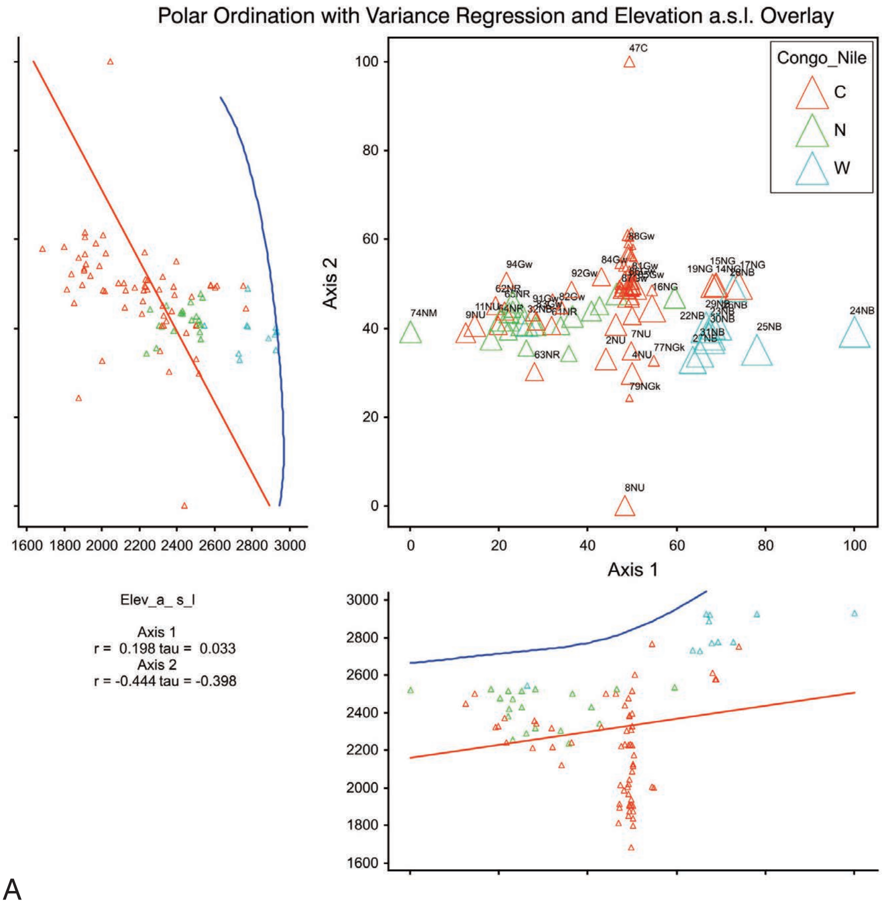


Figure 4.5: pane A (pane B below) Scatterplot of the sample plots in relation to axes one and two. The size of the symbols indicates the elevation a.s.l. Scatterplots on the left and below showing the ordination scores against the elevation a.s.l. Lower right scatterplot: Elevation a.s.l. against axis one; Upper left: Elevation a.s.l. against axis two. Superimposed red lines: least-squares regression lines; blue lines: envelope lines including roughly 95% of the samples (2SD); also represent the approx. upper bound of the overlay variable

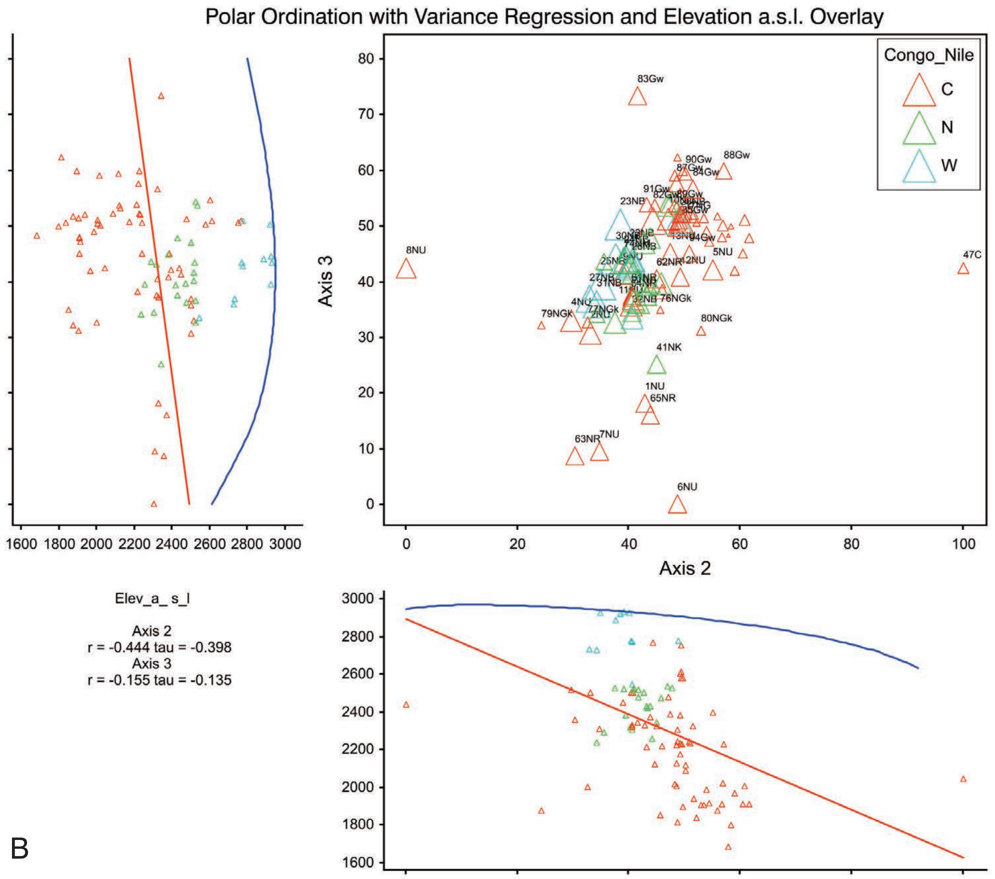


Figure 4.5: pane B Scatterplot of the sample plots in relation to axes two and three. See above textbox for interpretation.

Temperature, as should be apparent, is related to altitude and shows a corresponding trend (Fig. 4.6). The same is valid that has been stated for elevation. Here, conversely, the magnitude of the variable is larger for the samples from the Congo side, i.e., the mean annual temperature is higher. When looking more closely, it can be seen that for sites 9_{NU} and 11_{NU} the temperature is somewhat lower than for most of the other samples on the Congo side. While this might be part of the reason for the separation of the sites along axis one and, to some extent the placement of site 32_{NB}, the positioning of the Gishwati samples, however, seems to be founded elsewhere. Also, the samples from Ruzizi do not show an apparent temperature difference. At least axis two offers a small linear correlation with temperature, and the increase of temperature from the lower left to the upper right of the plot can be speculated (Fig. 4.6 B).

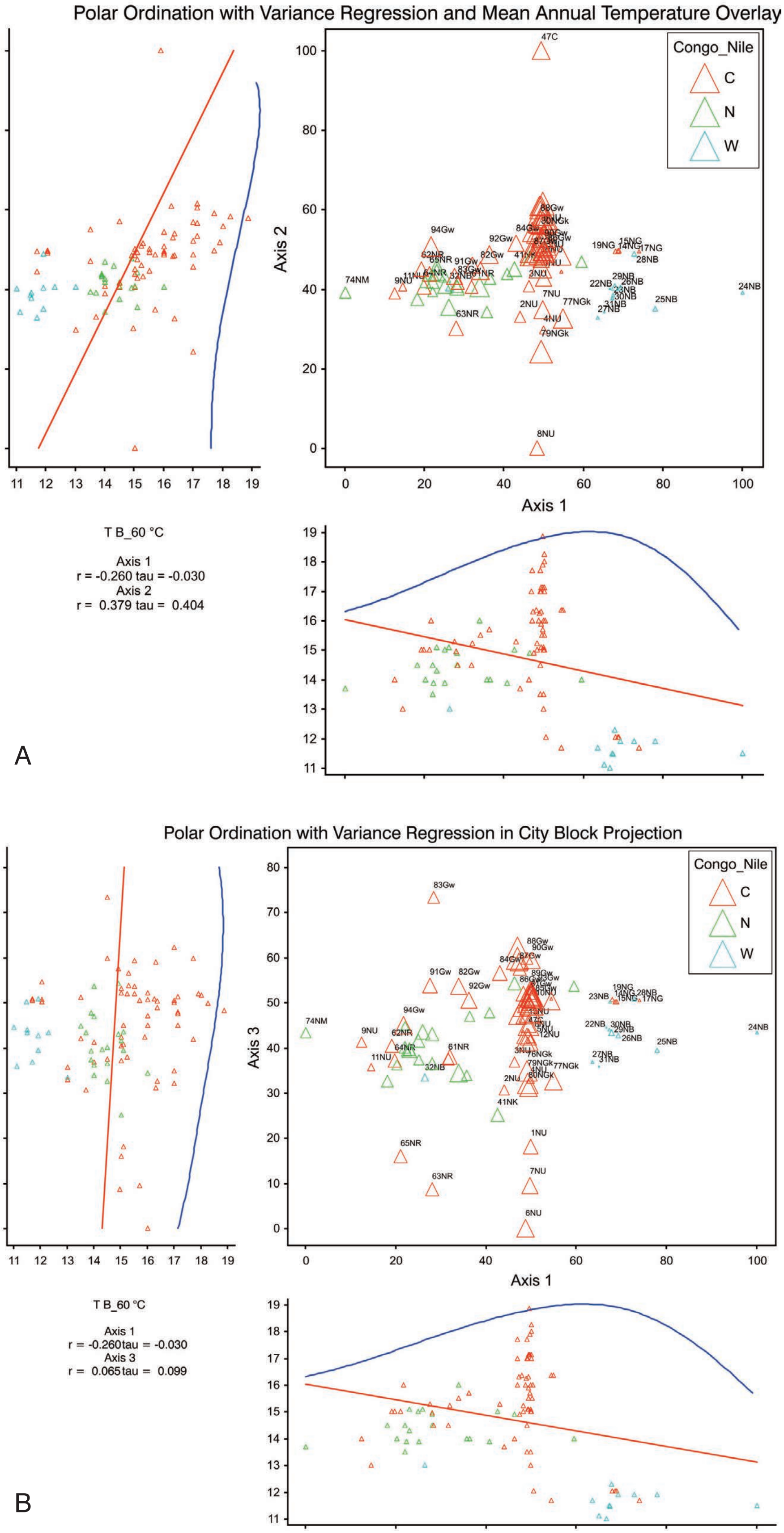


Figure 4.6: pane A and B (C below) Scatterplot of the sample plots in relation to axes one and two. The size of the symbols indicates the mean annual temperature in 2m above the ground as indicated by the temperature measured in 60 cm soil depth. See captions for Figure 4.5 for interpretation.

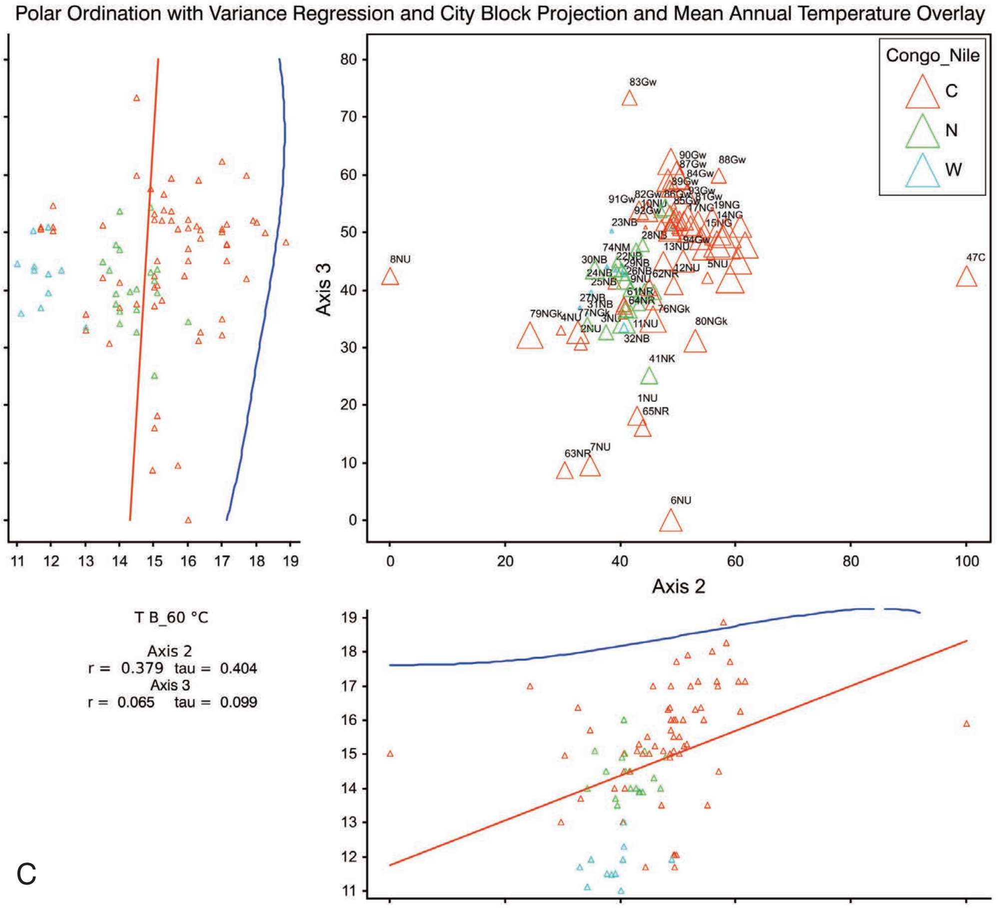


Figure 4.6: pane C; Scatterplot of the sample plots in relation to axes two and three. The size of the symbols indicates the mean annual temperature in 2m above the ground as indicated by the temperature measured in 60 cm soil depth. See captions for Figure 4.5 for interpretation.

The distance to the border of the forest (Fig. 4.7) seems to have some impact as well, and with a $r^2 = 0.18$ to axis one, the linear fraction might be one of the larger ones but still does not suffice as an explanation alone. As can be seen on axis one, the samples are spread out from left to right with an increasing distance from the forest margin. The same, though to a lesser extent, is true for axis two from top to bottom ($r^2 = 0.14$). Moreover, some exceptions can be seen when it comes to sample 32_{NB} and the samples around Uwinka, which have been separated from the rest of the samples from their location. This situation might partly be explained by the differences in temperature, as shown before. For the sites in Gishwati Forest, at least a partial explanation seems apparent. Samples 94_{Gw}, 91_{Gw} and 92_{Gw} are positioned within less than 300 m of the forest edge. The same is true for sample 86_{Gw} although it is not separated. Samples 83_{Gw} and 82_{Gw} surpass the 300 m by far. Hence, an explanation has still to be found. Further inspection of the plot draws attention to the sites on Mt. Muzimu. The horizontal distance to the forest edge might be quite small here, but the vertical one must not be neglected, which, as was shown in the preceding paragraphs, might be the main impact variable.

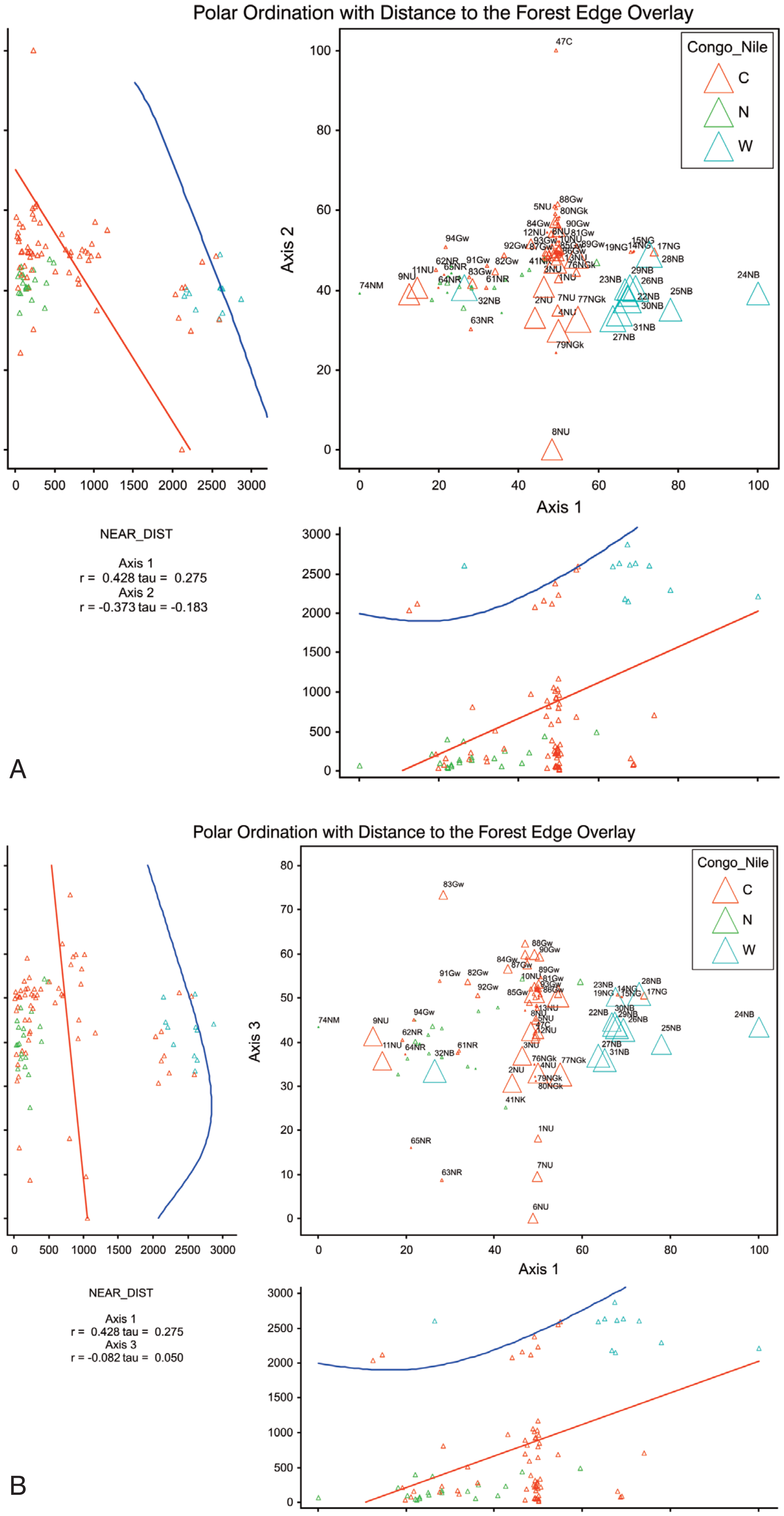


Figure 4.7: panes A and B; Scatterplots of the sample plots in relation to axes one, two and three, respectively. The size of the symbols indicates the distance to the forest edge. See captions for Figure 4.5 for interpretation.

The geological underground, when employed as a grouping variable, presents a picture in which the sites are somewhat separated by the different rock types (Figure 4.8). When we turn our attention towards the sites in Gishwati Forest mentioned above, we can see that they are all situated on granite rock/para- and orthogneiss with inclusions of undifferentiated sediment rock. This is not different from the other samples from Gishwati and many samples from the Nile side. As a result, the additional reasons for the separation of the sites along the first axis remain elusive. Site 32_{NB} is placed among the sites around Uwinka which are positioned on slate, mica-slate, phyllonites and minor quarzitic inclusions. Hence, a piece of the puzzle as to the cause of the separation of site 32_{NB} might be found here as well. For the separated sites from Uwinka, no further inference can be made. The samples from Ruzizi are all situated on the same geological underground as most of the sites from the Nile side of the watershed. Additional information on the similarity of the samples has thus been added. For sample 79_{NGk} no such inference can be drawn here since sample 80_{NGk} is positioned on the same geological material. Consequently, the separation of the samples along axis two remains unexplained. The sites at Musebeya have all been grouped, and it seems that geology has some impact besides precipitation and elevation. The same appears to be true for the sites at Cyamudongo Forest. Therefore, it seems that the geological component has an impact which with no substantial difference in elevation (Figure 4.9) as well as in precipitation (Figures 4.10 & 4.11) and in some cases in conjunction with the distance to the forest edge can co-determine species composition.

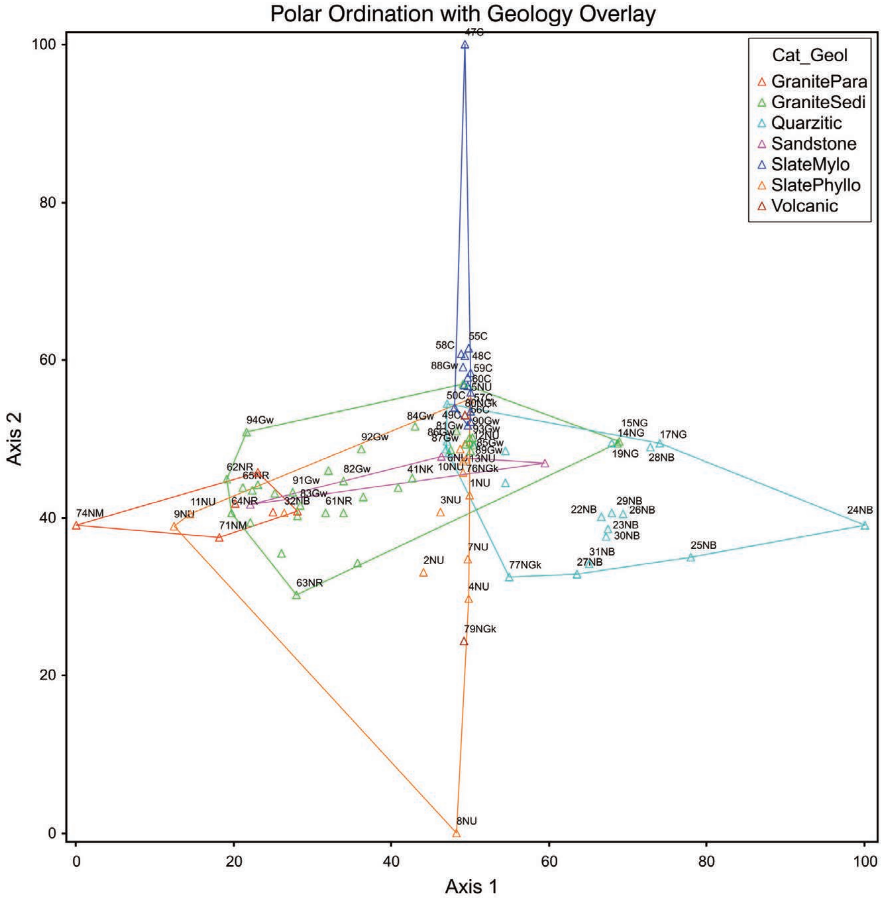


Figure 4.8: Scatterplot of the samples in relation to axes one and two. The geology was used as a grouping variable. The convex hulls mark the ordination space defined by each group.

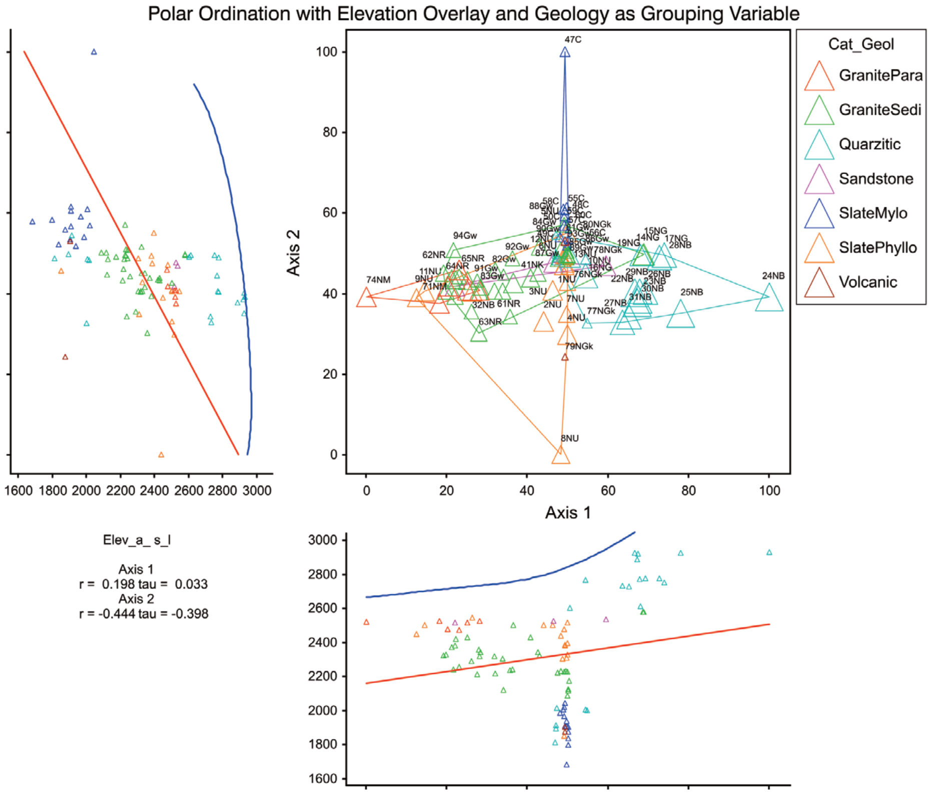


Figure 4.9: Scatterplot of the samples in relation to axes one and two. The size of the symbols indicates the elevation a.s.l. See captions for Figure 4.5 for interpretation.

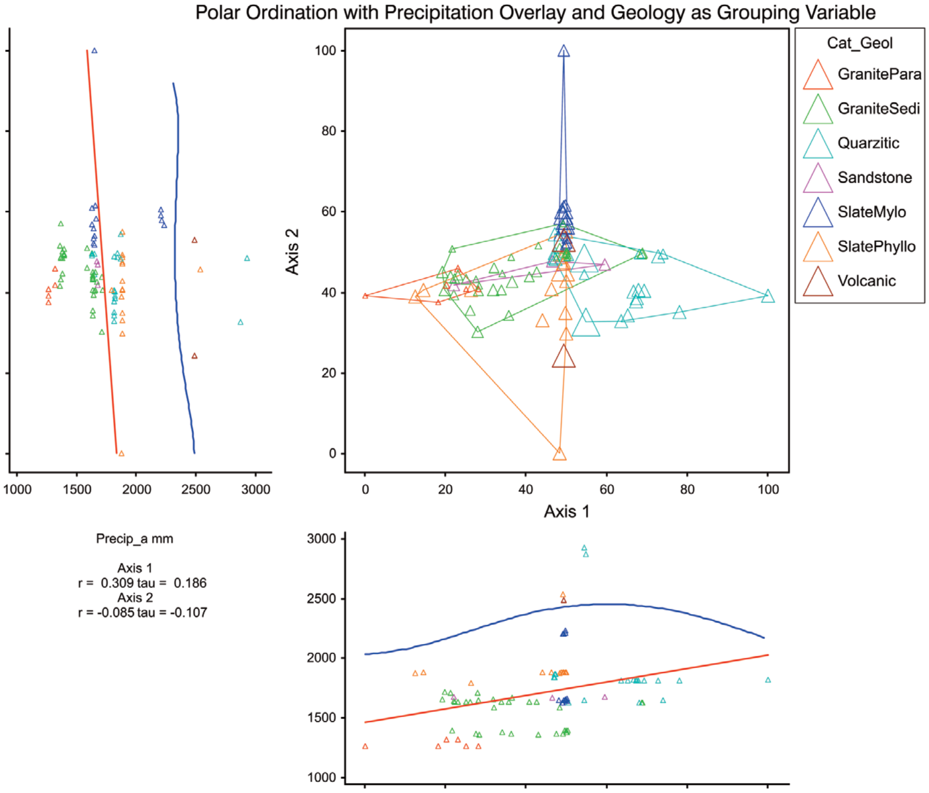


Figure 4.10: Scatterplot of the sample plots in relation to axes one and two. The size of the symbols indicates the mean annual precipitation. See captions for Figure 4.5 for interpretation.

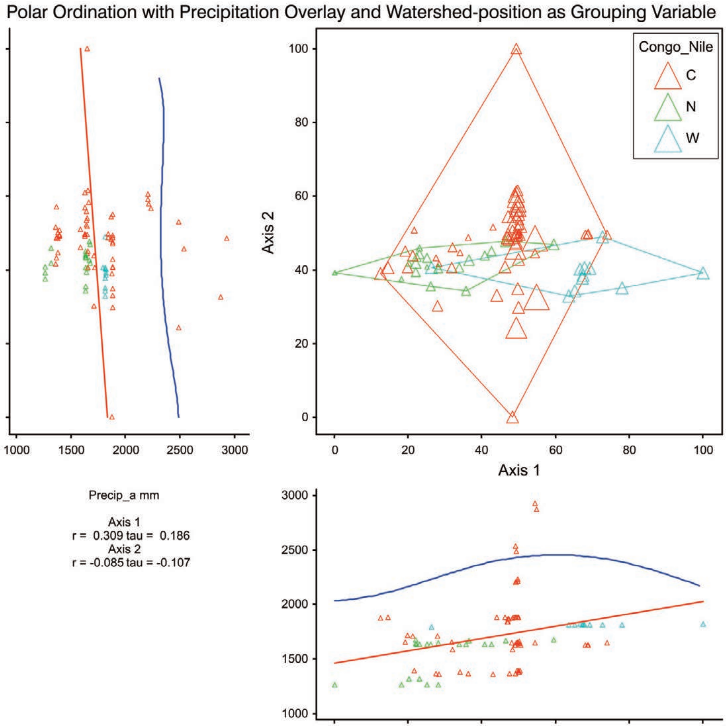
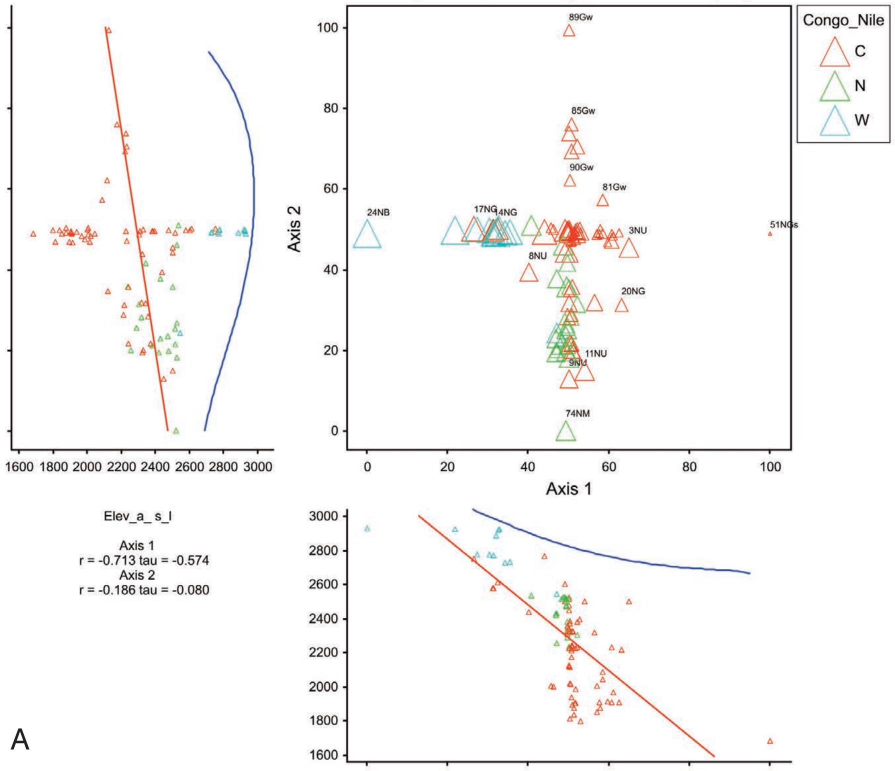


Figure 4.11: Scatterplot of the sample plots in relation to axes one and two. The size of the symbols indicates the mean annual precipitation. See captions for Figure 4.5 for interpretation.

An option in Polar Ordination is to force samples as endpoints of the axes by subjective choice. If a gradient is suspected to impact species patterns, the sample sites with the largest distances on this gradient can be chosen as endpoints. This selection has been done with the most salient and traditionally established environmental factors–elevation, precipitation, situation on the watershed as well as temperature. In another attempt, the largest geographical distance has been used to elucidate a possible impact.

Using the sampling sites with the largest elevational differences as endpoints leads to an extracted variation of 17.56% for the first axis of the original distance matrix. Despite the extracted variation of the consecutive axes being comparable, with 58.00% the cumulative variation extracted for the first three axes is lower than in the first run. In comparison to the first evaluation, the much lower result for axis one points to the possibility that the main gradient present in the data is not founded in elevation alone. This prospect is also illustrated by the ordination of the sites along axis two, i.e., in the middle of axis one. Still, the linear portion of the correlation with an $r^2 = 0.42$ clearly suggests that elevation is a major impact. Though elevation might impact species composition to a considerable percentage, it is still a combination of environmental factors which exert an influence. This inference underlines the results of the post-hoc correlation of elevation with the ordination axes undertaken before. As can be seen from the plot (Figure 4.12), the sites on Mt. Bigugu are clearly separated, and–with the according overlay of the mean annual temperature–the picture encompasses this impact too. The $r^2 = 0.38$ not only suggests other factors to be involved here as well, it might also indirectly give a hint that elevation does not integrate temperature alone. On the second axis, the segregation of the western and the eastern part is somewhat visible. Again, some sites in Gishwati Forest and some around the ranger stations at Uwinka and Ruzizi are ordinated amongst sampling sites situated on the Nile side of the watershed.


Polar Ordination with Elevation a.s.l. Overlay and Watershed-position as Grouping Variable

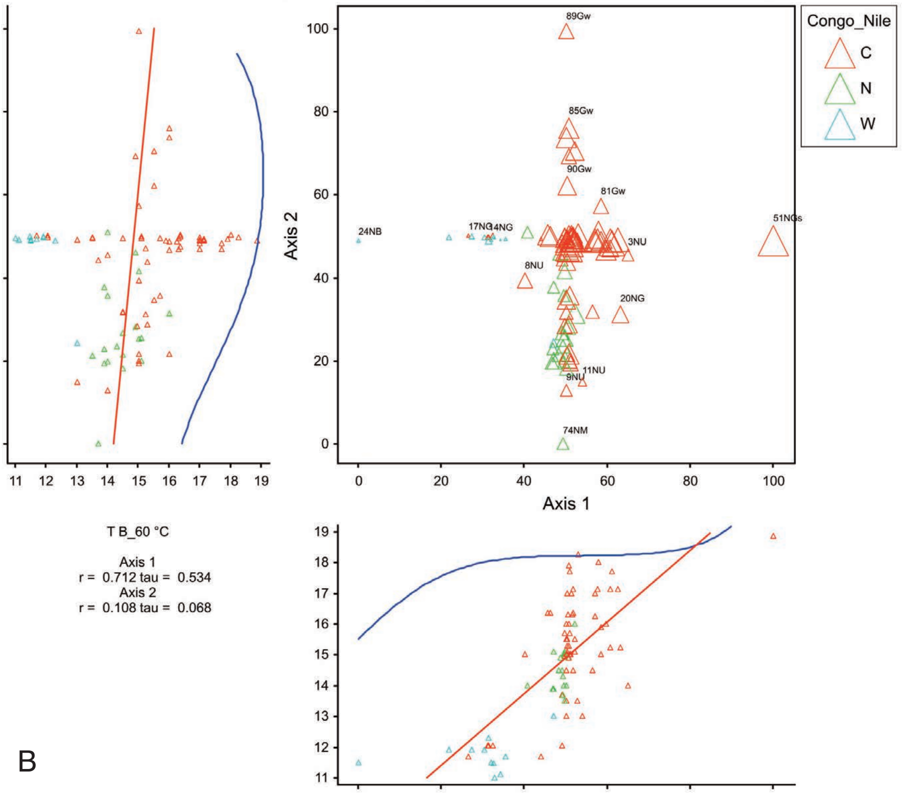

Polar Ordination with Temperature Overlay and Watershed-position as Grouping Variable

Figure 4.12: panes A and B; Scatterplot of the sample plots in relation to axes one and two. The endpoints for axis one were chosen along the largest elevational difference. The size of the symbols indicates the elevation a.s.l and the mean annual temperature, respectively. See captions for Figure 4.5 for interpretation.

Much the same is valid for the trial run using the largest differences in precipitation as endpoints for the first axis. The extracted 20.20% of the original distance matrix on the first axis are somewhat higher than for elevation as the main gradient. However, they are still falling short of the completely objective first run of the analysis. Although the following axes extracted a little more of the variation, the 56.27% extracted by the first three axes still lead to the same conclusion of more than one impact factor being of importance. In other words, no single impact factor can be elected as responsible for species composition alone. Figure 4.13 shows that the distinction between the Nile and Congo side of the watershed is not as clear as before. Still, precipitation on the Congo side is somewhat higher. The four sites at the lower end of axis three are situated at the summit region of Mt Muzimu. In the image, the third and first axes are shown, and precipitation has also been set as an overlay, so the size of the symbols is related to the magnitude of the variable.

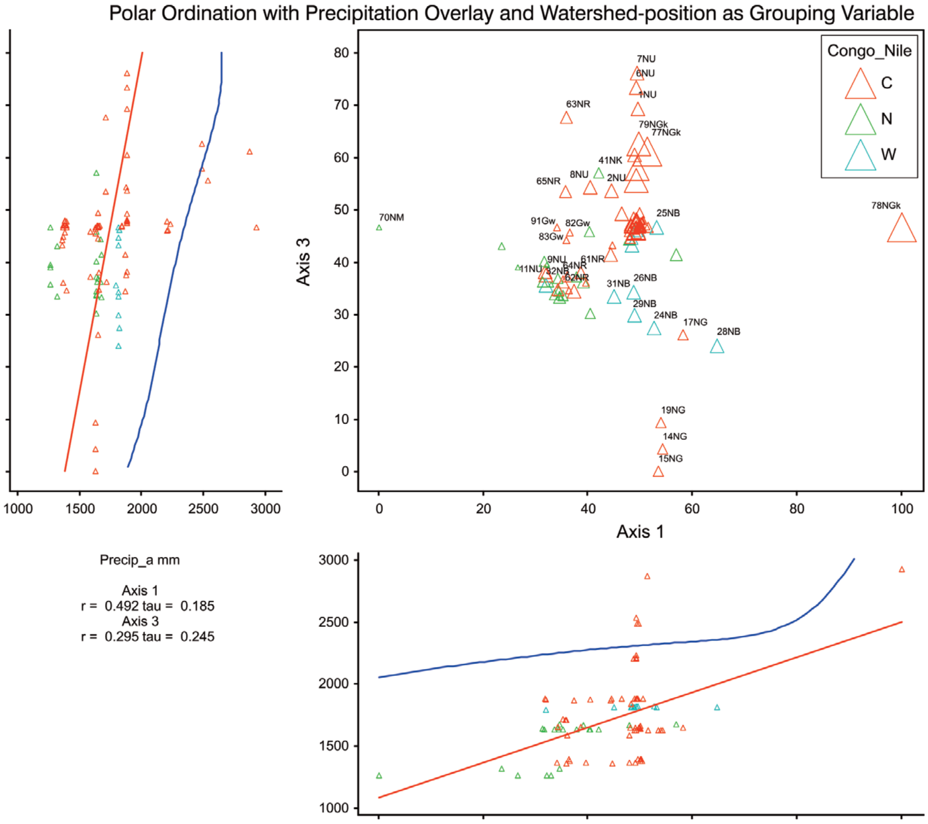


Figure 4.13: Scatterplot of the sample plots in relation to axes one and three. The endpoints for axis one were chosen along the largest difference in precipitation. The size of the symbols indicates the mean annual precipitation. See captions for Figure 4.5 for interpretation.

It is common knowledge that the distance from the fringe of the forest impacts species composition to a great extent. Using the sample sites having the shortest and the largest distance from the forest margin as poles for the first axis extracts 13.50% of the variation of the original distance matrix on the first axis. Though this falls more than short of the objective run, some impact on species composition is still measurable. Although the responses are unimodal for the most part, the r^2 for the first axis reaches 0.30. Besides the bulk of the sites being ordinated along axis two and within the medium range of both axes, the gradient depicted along the first axis also contains differences in elevation to a larger extent since the ends of the axis are composed of the samples from Cyamudongo and from Mt Bigugu, which–in turn–also represent the highest and lowest elevations, respectively. With an extracted 59.14% of the original variation on the first three axis, the overall result is in the same range as for the former two attempts. The plot (not shown) did not reveal any new insights.

Though fairly redundant, the mean annual temperature has been used to set subjective endpoints as well. The first axis extracted 16.87% of the variation from the original distance matrix rendering the mean annual temperature as an impact factor among others, which, considering the results above, does not come as a surprise. Though the following axes extracted mostly a greater variation than in the completely objective attempt, the variation depicted on the first three axes amounts to only 45.35%. The same conclusions as in the previous paragraph are applicable. The plot did not elucidate new results as well (not shown).

As it has been stated that there are marked differences in vegetation composition, the sample sites with the largest distance in an east-west direction between them have been chosen as endpoints of the first axis. This approach then extracted 27.11% of the variation present in the original distance matrix with the first axis. The succeeding axes extracted amounts comparable to the objective approach, and the variation extracted by the first three axes amounts to 65.83%. Though Figure 4.14 does not reveal any new information, the impression, which also can be taken from the other figures, that the sites draining towards the Congo River are more similar to each other than the sites draining into the River Nile, is somewhat raised by it. We shall see if that assumption can be corroborated in further analyses.

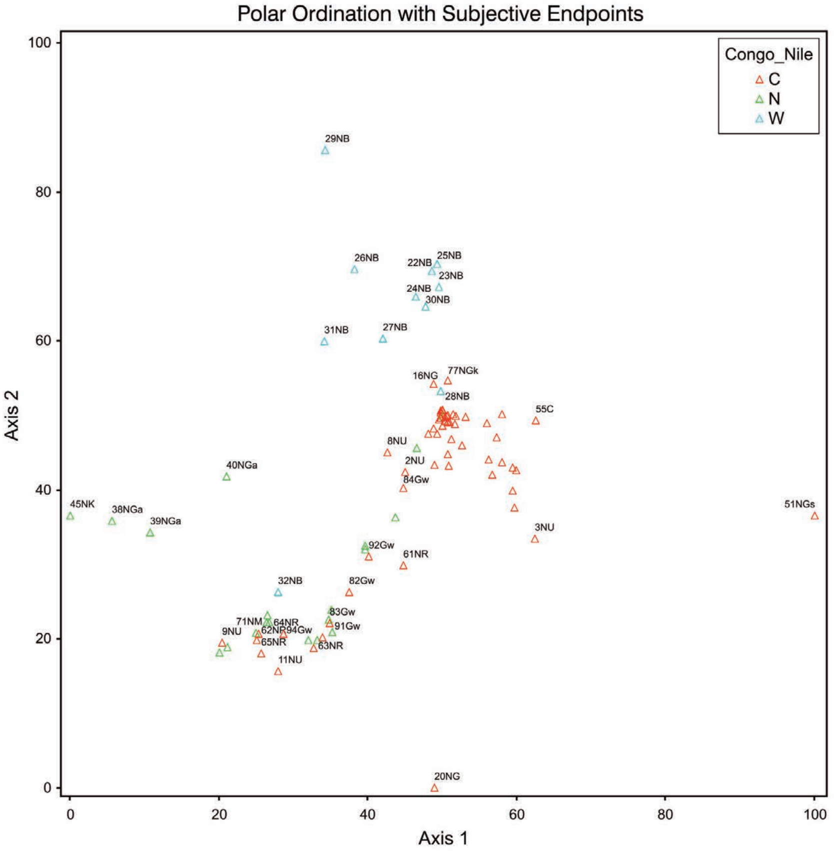


Figure 4.14: Scatterplot of the sample plots in relation to axes one and two. The endpoints for axis one were chosen along the largest distance in east-west direction.

Axis:	1			2			3		
Independent Variables	r	r-sq	tau	r	r-sq	tau	r	r-sq	tau
Inclination [°]	-0.062	0.004	-0.038	0.089	0.008	0.124	0.22	0.049	0.119
Precipitaion / a [mm]	0.309	0.096	0.186	-0.085	0.007	-0.107	-0.263	0.069	-0.267
Elevation a.s.l [m]	0.198	0.039	0.033	-0.444	0.197	-0.398	-0.155	0.024	-0.135
Temperature /a [°C]	-0.26	0.068	-0.03	0.379	0.144	0.404	0.065	0.004	0.099
Distance to Forest Margin [m]	0.428	0.184	0.275	-0.373	0.139	-0.183	-0.082	0.007	0.05
Insolation [Wh/m²]	0.185	0.034	0.082	-0.249	0.062	-0.27	-0.227	0.052	-0.116
[Na] [mg/kg]	-0.009	0	0.001	-0.007	0	-0.059	-0.175	0.031	-0.164
[Al] [mg/kg]	-0.364	0.133	-0.303	-0.158	0.025	-0.13	-0.422	0.178	-0.288
[K] [mg/kg]	-0.014	0	-0.053	0.062	0.004	0.035	-0.192	0.037	-0.168
[Ca] [mg/kg]	0.157	0.025	0.181	0.275	0.076	0.116	0.226	0.051	0.192
[Mg] [mg/kg]	0.097	0.009	0.103	0.379	0.143	0.102	0.175	0.031	0.085
[PO] [mg/kg]	0.099	0.01	-0.002	0.037	0.001	-0.055	0.165	0.027	0.023
[N] [mg/kg]	-0.172	0.03	-0.168	-0.196	0.038	-0.178	-0.521	0.271	-0.397
[C] : [N]	0.175	0.031	0.041	-0.448	0.201	-0.367	-0.49	0.24	-0.378
[C] [mg/kg]	-0.091	0.008	-0.13	-0.302	0.091	-0.27	-0.586	0.343	-0.454
pH	-0.001	0	0.043	0.44	0.193	0.377	0.444	0.197	0.429
electrical conductivity [μS/cm]	-0.083	0.007	-0.12	-0.179	0.032	-0.206	-0.53	0.281	-0.434
CEC	-0.163	0.026	-0.127	0.181	0.033	0.054	-0.186	0.034	-0.189
Ca / Al	0.047	0.002	0.191	0.159	0.025	0.157	0.104	0.011	0.246
Mg / Al	0.062	0.004	0.209	0.234	0.055	0.145	0.116	0.014	0.222
Drillable Soil Depth [m]	0.005	0	-0.377	-0.217	0.047	-0.208	-0.119	0.014	-0.234
kf	0.181	0.033	0.069	0.167	0.028	0.155	0.215	0.046	0.19
Stonecontent [%]	0.372	0.138	0.201	0.087	0.008	0.185	0.182	0.033	0.208
Topographical Wettness Index	0.211	0.045	0.079	-0.13	0.017	-0.168	-0.245	0.06	-0.155

Table 4.2: Pearson and Kendall Correlations of the independent variables with Ordination Axes after Polar Ordination with Variance Regression.

In a final partially subjective attempt, the largest distance between two plots has been determined, and these plots then became the endpoints of the first ordination axis. With 22.99% of variation extracted from the original distance matrix on the first axis, the geographical distance seems to be one of the major impact factors on species composition. Further axes extracted amounts comparable to the all-objective attempt. The result for the first three axes gives 62.19% of extracted variation. Although the ordination changed slightly, new information could not be gained from the scatter plot (not shown).

In a last explorative pursuit, biplots will be utilized to find possible impact factors which may have gone unnoticed so far. However, the table of correlations with the ordination axes (Tab. 4.2) does not promise too much of a revelation. The highest r^2 value is 0.34, and the cut off for displaying a variable in the plot has been set to 0.09. It has already been stated that elevation a.s.l., the distance to the forest margin, mean annual temperature and mean annual precipitation do have some impact.

Although most of the soils are practically stone-free in the A-horizon, a medium correlation of the estimated stone content can be seen from Figure 4.15 A. The $r^2 = 0.14$ does not point to much of an impact. Some of the samples with increased stone content were grouped together by ordination (plot not shown). Most of the samples on the distal end of the vector are situated on shallow soils limited by rock; these tend to be the same samples that were grouped by stone content. In fact, both variables show some correlation. It remains to be seen whether or not plant combinations are affected by the variable.

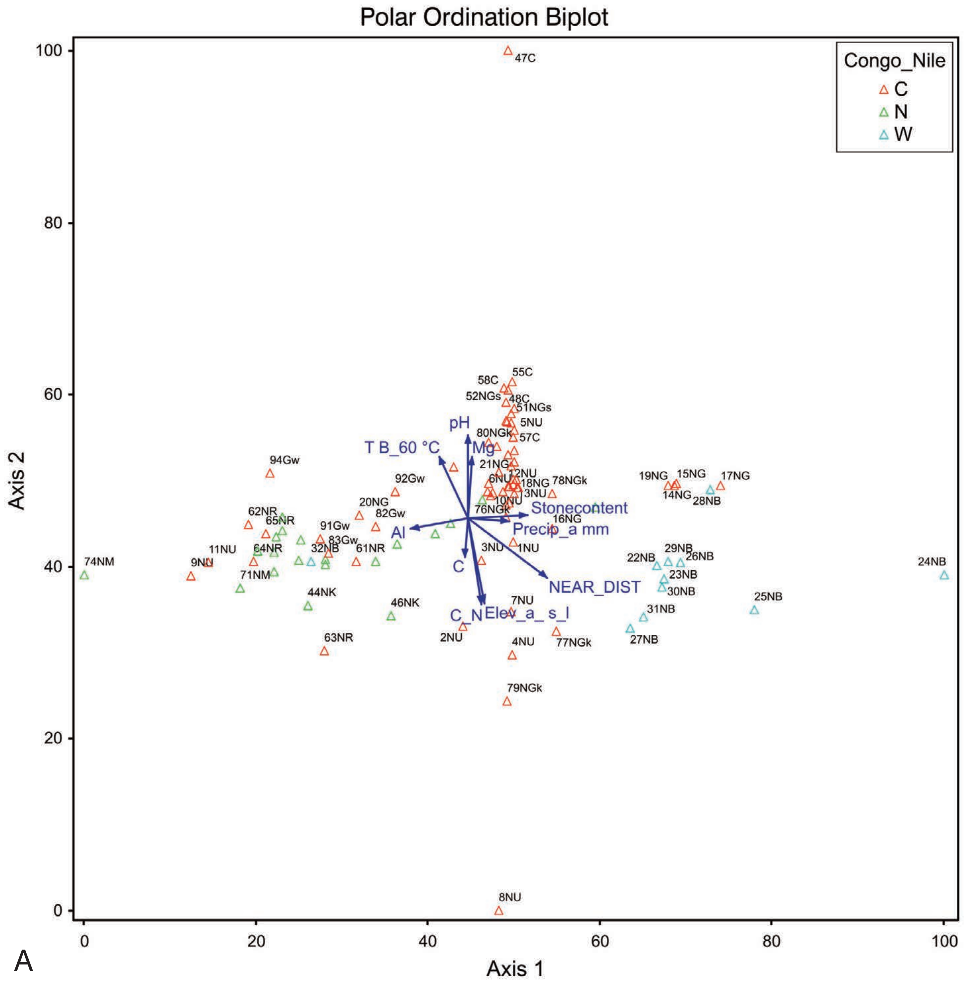


Figure 4.15: pane A; Biplot of the samples in relation to axes one and two. Variance regression was used to determine the endpoints of the axes. The city block projection was used to display the results. The cut-off value for the independent variables is set at $r^2 = 0.09$.

From the same figure (4.15 A, see also 4.15 E), it can be seen that the carbon to nitrogen ratio of the soil may impact species composition as well. We can see from the graph that the elevation vector and the [C]:[N] vector point in the same direction, and indeed a $r^2 = 0.38$ points to a heightened correlation between the two. Since [C]:[N] has its largest correlation with axis three and elevation is correlated most with axis two, the respective plot (4.15 B) shows the relation between the two more clearly. What can also be seen more distinctly is the relation of soil reaction to the variables. Here, pH values show a medium to large negative correlation with both (see Fig.: 4.15 D). Thus, the impact of the heightened carbon concentration as illustrated by $r^2 = 0.34$ to axis three, might indeed be somewhat smaller than the coefficient might suggest (Annex 5). As expected, the Nitrogen concentration [N] and the Carbon concentration [C] are correlated to the third axis as well. Moreover, the electrical conductivity (EC) also seems to show some correlation to the third axis.

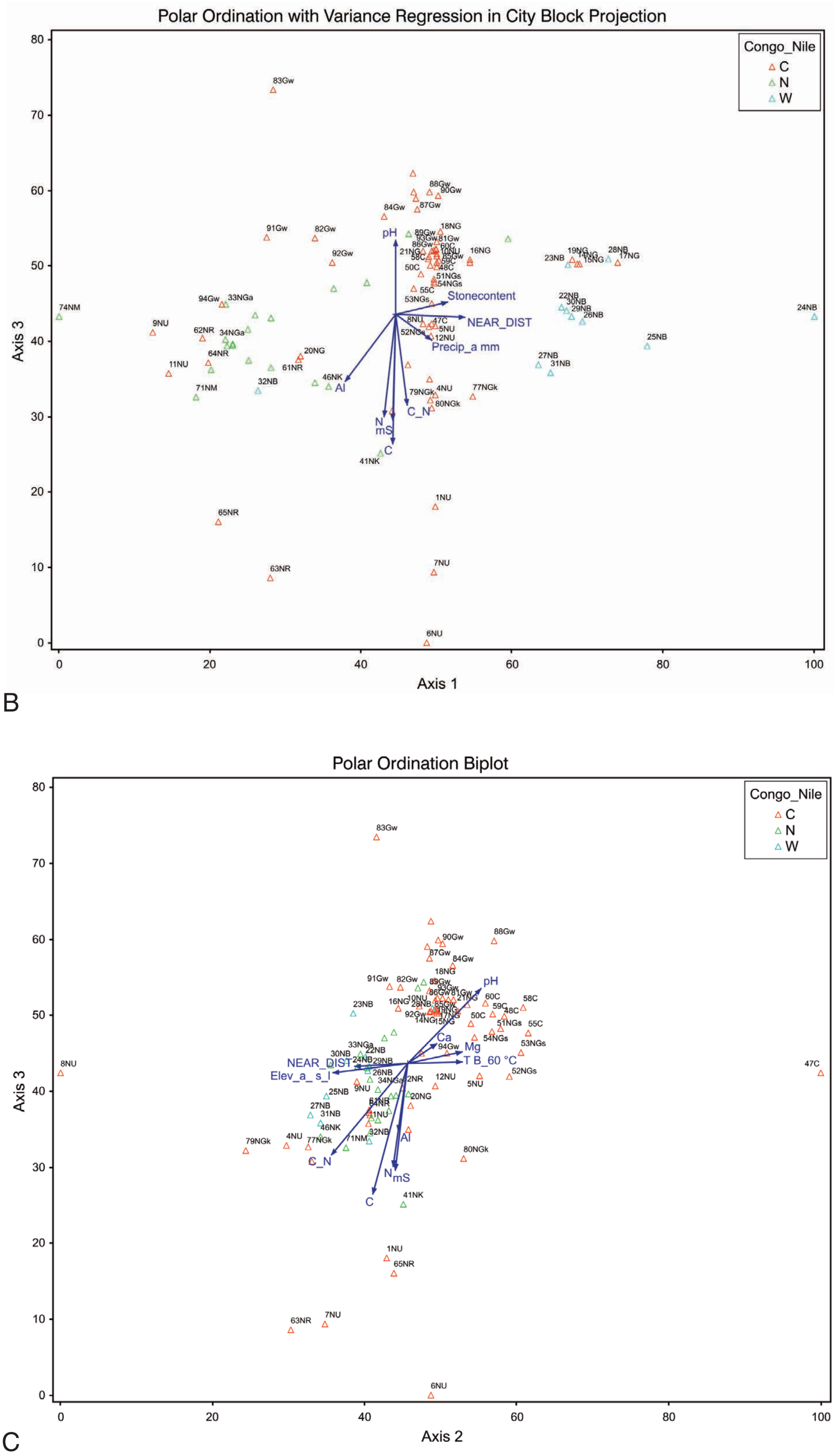
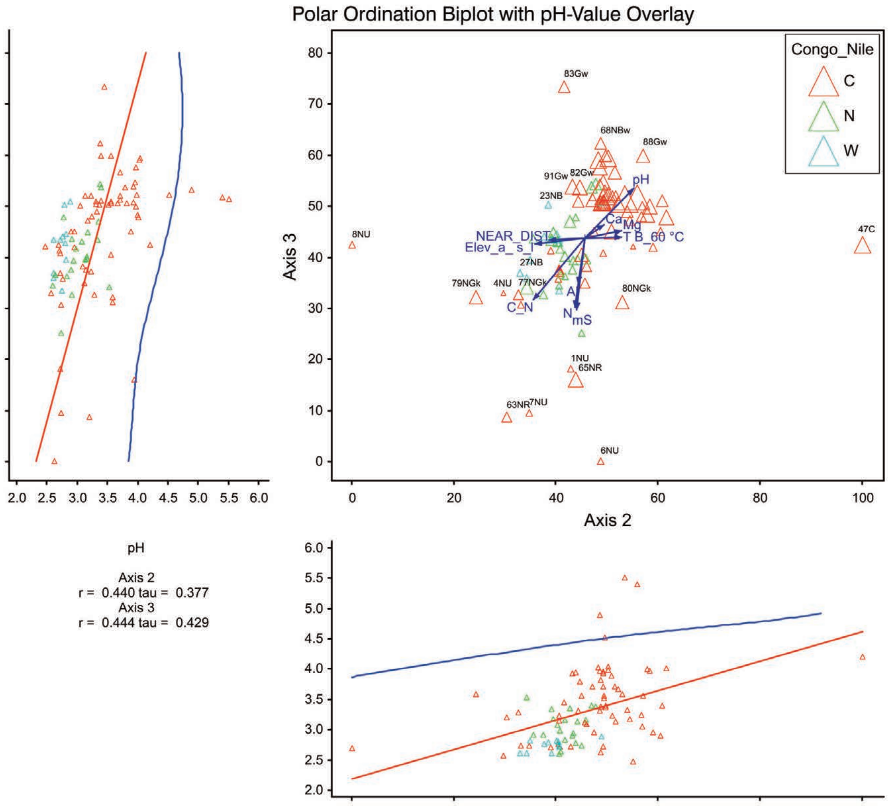


Figure 4.15: panes B and C; Biplot of the samples in relation to axes one and two. Variance regression was used to determine the endpoints of the axes. The city block projection was used to display the results. The cut-off value for the independent variables is set at r² = 0.09.

When it comes to Nitrogen, it can be seen that the vector runs in the same direction as the [C]:[N] ratio and that the relation is manifested by a medium correlation coefficient (Tab. 4.2). The same is true for the [C], although the correlation coefficient exhibits an almost linear positive relationship to the [N] and a large negative correlation to pH. Since an increasing [C]:[N] ratio comes with either a decreasing [N] or an increasing [C], the concentration of carbon must be increasing here in a rate as to keep the ratio increasing while the Nitrogen concentration increases as well.



D

Figure 4.15: panes D; Biplot of the samples in relation to axes one and two. The pH-value was used as an overlay. The cut-off value for the independent variables is set at $r^2 = 0.09$.

Since very little Nitrogen and Carbon are contained in the soil parent material and mineral soil substance, an accumulation of organic matter in the A-horizon as a result of a decreasing pH and / or decreasing temperatures at higher altitudes can be presumed. In fact, Kauffman, Sombroek & Mantel (1998) stated that the soil nutrient retention capacity emanates to about 90% from organic matter and that the same matter is the source for 90-95% of nitrogen. As we well know, litter decay depends not only on the litter itself but on temperature and pH too. Acidification might as well be intensified by elevated precipitation. This inference can be derived from the figures at hand and the medium correlations among the variables (Annex 5).

Possible reasoning may be as follows. McCauley, Jones & Olson-Rutz (2017) have stated that microbial activity is significantly reduced at and below pH 5 and that fungal activity is predominant at a low pH. According to Vareschi (1980) who cited Finck (1963), the thermal optimum for bacterial and fungal activity in tropical forests is at 35°C and 23°C, respectively.

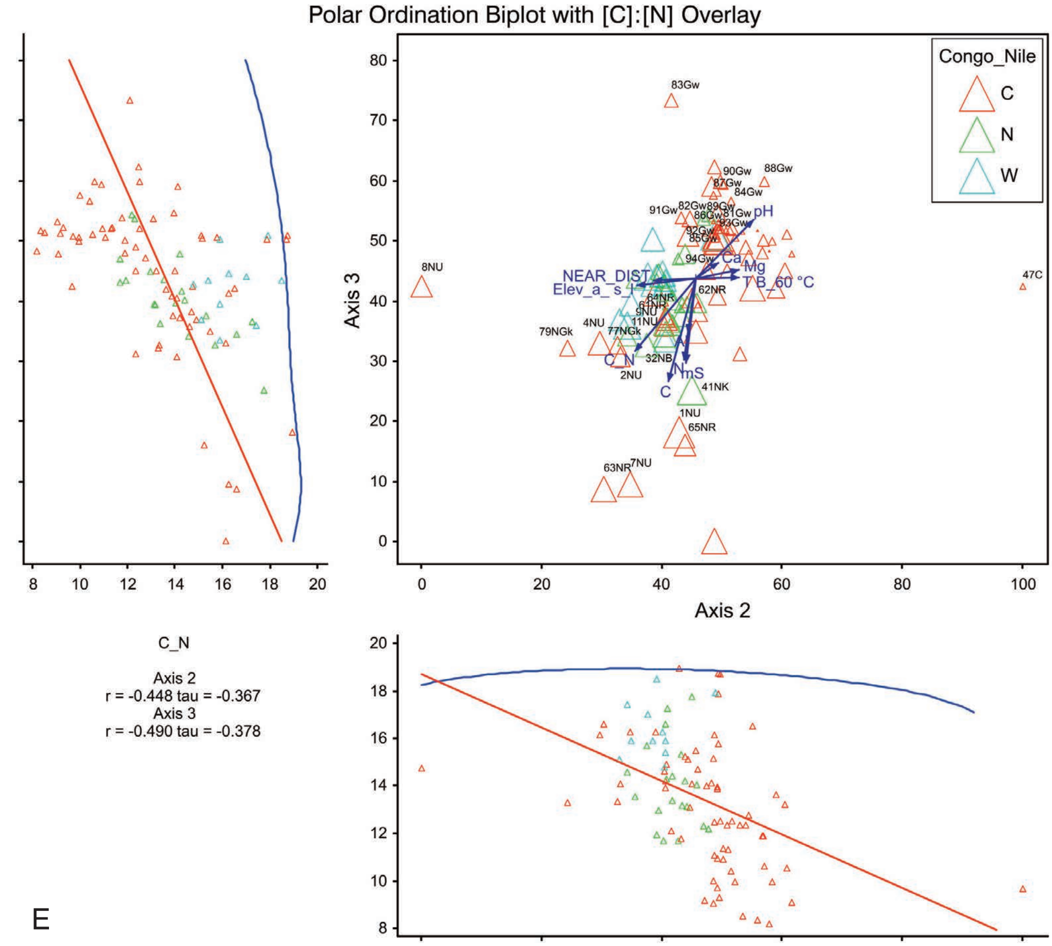


Figure 4.15: pane E; Biplot of the samples in relation to axes one and two. An overlay of the [C]:[N] ratio was used. The cut-off value for the independent variables is set at $r^2 = 0.09$.

It, therefore, becomes conceivable that fungal activity drives soil development (see also VARESCHI 1980). Moreover, this viewpoint allows for the conjecture that mineralisation within the samples is lowest when the temperature is at its minimum as well. The same could be inferred for pH. Here it is not necessary for both minima to coincide, but conjoined impacts are of course an option. From here, we infer that humification is predominant. As VARESCHI (1980) described it, a permanent humus horizon will not be established, but the highly disperse and acidic substances are to be found in the topsoil (Oberboden). There, they will only shortly bind onto clay particles and be quickly replaced by H^+ (IBID). This outcome then stems from the acid conditions which are well documented, and which exhibit strong negative correlations to Carbon, Nitrogen, EC and the [C]:[N] ratio. With that, our above presumption gains more strength.

Tropical soils, especially the ones at hand, are heavily impacted by leaching. The main source for nutrition is the organic material, mostly litter. During litter decay, anions are the first to be released (see MCCAULEY ET AL. 2017), which–under the given circumstances–are the only tangible explanation for the retention of EC. As we have seen above, mineralisation is slowed down by acid conditions and organic material can accumulate. The negative correlation with axis three and the pH of the electrical conductivity of the soil, a measure for the ecologically effective salt content, is thus also explicable. In the same way, the increase of [C]:[N], [C] and [N] blend into the picture. Accordingly, electrical conductivity is driven by the accumulation of organic material, which is directed by acid conditions slowing down the decay. Therefore, more material is washed in from the O-horizon into the A-horizon where decomposition continues and thereby increases EC. In this context, another observation became more apparent when plotting axis two and three in the same diagram. It can be read from the graph, that with some exemptions, the pH appears to be partially higher for the samples from the Congo side, which falls into place with the above considerations. The graph also illustrates that elevation not only integrates temperature but pH, via temperature, as well.

Plotting axis three and one depicts the largest correlations of the Aluminium concentration [Al] with the ordination axes. Here, also the relations of the [N], the [C], pH and the EC to [Al] can be best noted (Fig. 4.15 B). Figure 4.15. C depicts the relations of aluminium, calcium and magnesium with the axes and among the elements. All of them show medium correlations, at best. Since an elevated [Al] can be a characteristic of acid soils, the negative correlation to the alkaline [Ca] and [Mg] can be explained. Consequently, it is unsurprising that the sites on the Congo side seem to have a higher [Ca] and [Mg]. The elevated [Ca] for some samples from Mt Bigugu might originate in the accumulated organic matter mentioned above. As the linear correlation is negligible, we will see if the unimodal response visible in the graph (not shown) is of merit in elucidating the gravity of the environmental variables in more appropriate evaluations. Though the r^2 values of the correlations of [Al] with the axes do not signal a significant impact either, attention will still be paid to them. KAUFFMAN ET AL. (1998) stated that Aluminium toxicity can occur when high levels of exchangeable Al are present. According to them (IBID.), 33% and 30% of the dominant soils in the humid tropics show a moderate to very serious aluminium toxicity.

Before concluding the polar ordination section, we will summarise what we have learned. The traditionally conveyed factors precipitation, altitude / mean annual temperature, position in respect to the watershed and geology do impact species composition in a joined manner. It has also been noticed that some soil properties may have more impact than previously assumed. Although, it remains to be seen whether or not the correlation between *Syzygium parvifolium* and the Carbon and Nitrogen content as well the EC may lead to a circular reasoning. WEKESA, MARANGA, KIRUI, MUTURI, &GATHARA (2018) also found this correlation but failed to ask if this may be caused by the leaf litter of the tree itself. The question might also be raised due to their finding that soil organic carbon had no significant impact on the abundance of the most abundant tree species in their study. In our study another species has its main abundance where EC, [C] and [N] are higher, *Alchornea hirtella*. The species bears coriaceous leaves as well which under the given climatic conditions might likewise be decomposed more slowly. It remains that the often-found positive correlation between EC and pH seems not to be valid under the environmental conditions that govern soil development and litter decay in the study area (JOHNSON ET AL., 2001). As with environmental variables mentioned before, the soil parameters are correlated among each other which than results in integrated effects as well. Thus, correlation coefficients are not to be interpreted independent of each other. Another circumstance noticed as well by WEKESA ET AL. (2018) is the dependency of pH and EC on the distance to the forest edge. This result will be kept in mind and discussed at a later point.

It has been shown that environmental factors do not act on their own. They depend on each other may it be directly or indirectly. We shall see in further analyses, if all the environmental factors should remain in the same analysis step or if they should be evaluated as covariables in a partial analyses framework.

4.1.2 Principal Coordinate Analysis

Due to the critique that Polar Ordination has received and the fact that it has been widely ignored by science, another indirect ordination technique was applied. Following the considerations pertaining to the choice between non-metrical multidimensional scaling (NMDS) and principal coordinate analysis (PCoA), the latter was chosen. A comparison of the two can be taken from BORCARD ET AL. (2018). If in the following not all axes are shown, the axes displayed are of relevant explanatory value or display the highest correlations to the respective factors shown.

Though the ordination plot differs completely at first glance, the result is, in fact, not that different. When examining Figure 4.16 A, it can be seen that the sample sites on the respective sides of the watershed are somewhat well separated. The sites in Gishwati Forest and close to Uwinka still show more similarities to the sites located on the Nile side as do the samples from Ruzizi. The same is true for plot 32_{NB} on the foot of Mt Bigugu. From the plot it is also visible that the sites on Mt Bigugu are not that well separated from the sites on the Congo-side of the watershed. Especially plot 28_{NB} and some plots on Mt Muzimu as well as plot 23_{NB} and 16_{NG} on Mt Bigugu and Mt Muzimu, respectively, are positioned quite close. Plot 20_{NG} is also positioned closely to the samples from the Nile side of the watershed. The sample from Gisovu, which is not positioned on Mt. Muzimu, seems to bear some similarities to the Ruzizi samples as well. On the other hand, sample 21_{NG}, which is only a few metres apart from 20_{NG}, has been ordinated at quite some distance along axis one. So far neglected, two samples from around Gahurizo have been placed among the Congo-side-samples (35_{NGa}, 36_{NGa}) along axis one. A bit less pronounced, the unimodal responses along the axes are still visible. For axes one, there might be a bi-modal distribution present. After Polar Ordination failed to elucidate the main gradient on said axes, it remains to be seen if PCoA is capable of following through.

Here, the markedly lower variance extracted by PCoA along the first three axes does not seem promising. For the first axis, 14.35% of the original variance was extracted. The second axis displays 7.82% and the thrid axis 7.62% of the original variance. Thus, the cumulative extracted variance amounts to raw 29.79% or to corrected 21.81% (see 2.6.1.2).

	R Squared	
Axis	Increment	Cumulative
1	0.073	0.073
2	0.088	0.161
3	0.102	0.263

Axis pair	r	Orthogonality, % = 100(1-r²)
1 vs 2	0	100
1 vs 3	0	100
2 vs 3	0	100

Table 4.3 a: Left: Coefficients of determination for the correlations between ordination distances and distances in the original n-dimensional space
Right: Increment and cumulative R-squared were adjusted for any lack of orthogonality of axes.

Depicting axes one and three together, the separation between the three main divisions becomes clearer. The samples positioned on Mt Muzimu are not only ordinated in close proximity on either axis but are also very close to the sites on Mt Bigugu, a fact that has been neglected so far (Fig. 4.16 B). Axis one still shows a possible bi-modal distribution while axis three demonstrates a uni-modal one with the modus shifted to the distal end of the axis.

In a plot of the second and third axes, the sites on Mt Bigugu and Mt Muzimu are a bit more separated. The sites in Gishwati Forest, which have been previously plotted close to the sites draining towards the River Nile, are more clearly separated from them, while the Gishwati samples themselves have been arranged more closely. The overall separation between the Nile and the Congo sites is not any more pronounced (Fig. 4.16 C).

In the following, the same environmental parameters were examined as before. The choice was based mainly on the correlation coefficients computed by PC-Ord during the ordination. These were somewhat higher and, in some cases, more consolidated than for Polar Ordination. Since PCoA is claimed to be distortion free when it comes to the projection onto two dimensions, the increase might be due to that (BORCARD ET AL., 2018).

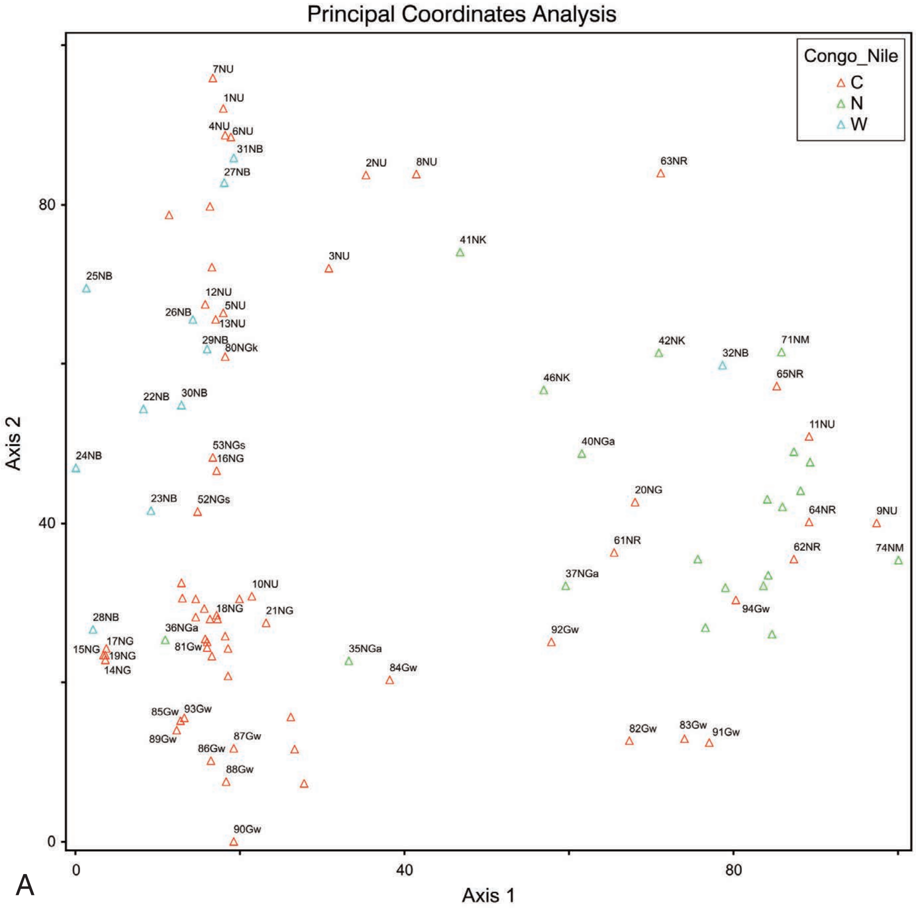
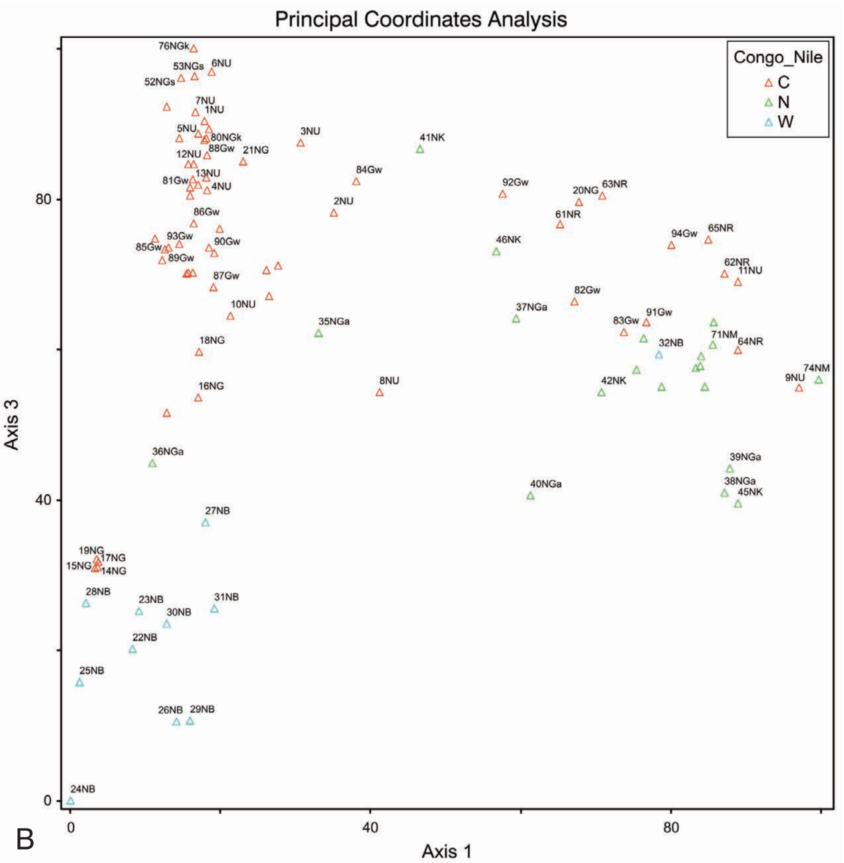


Figure 4.16: panes A and B; Scatterplot of the samples resulting from PCoA. The position on the watershed was used as a grouping variable.



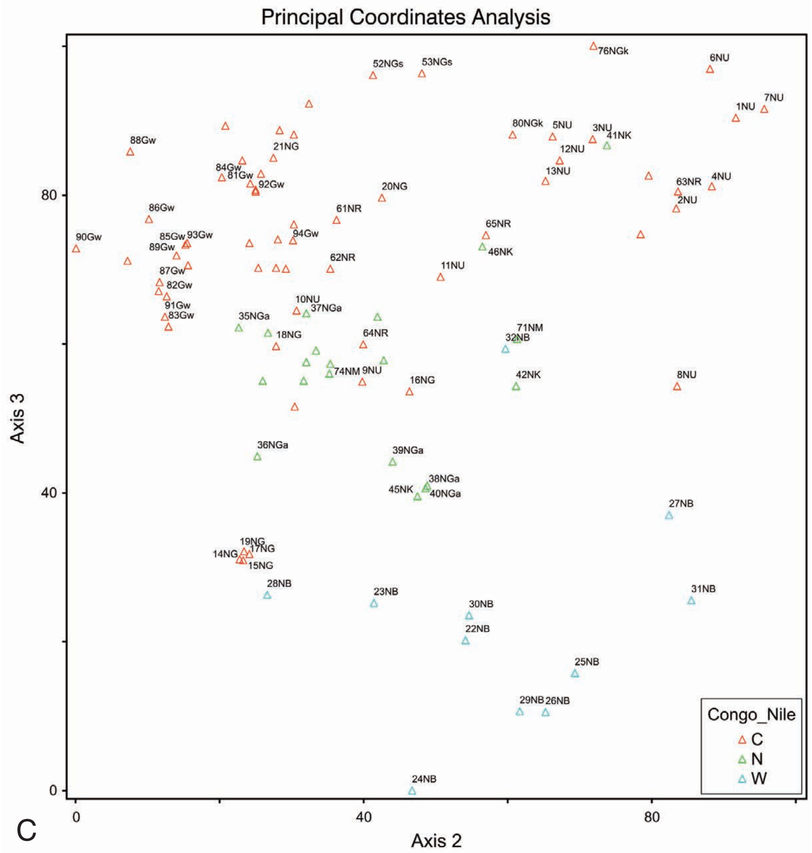


Figure 4.16: pane C; Scatterplot of the samples resulting from PCoA. The position on the watershed was used as a grouping variable.

Axis:	1			2			3		
Independent Variables	r	r-sq	tau	r	r-sq	tau	r	r-sq	tau
Inclination [°]	-0.055	0.003	-0.02	-0.221	0.049	-0.156	0.271	0.073	0.177
Precipitaion / a [mm]	-0.365	0.133	-0.206	0.44	0.194	0.37	0.123	0.015	0.132
Elevation a.s.l [m]	0.097	0.009	0.049	0.299	0.089	0.21	-0.735	0.541	-0.49
Temperature /a [°C]	-0.015	0	-0.056	-0.238	0.057	-0.186	0.735	0.54	0.486
Distance to Forest Margin [m]	-0.287	0.082	-0.206	0.405	0.164	0.101	-0.428	0.183	-0.094
Insolation [Wh/m^2]	-0.002	0	-0.013	0.291	0.085	0.188	-0.39	0.152	-0.198
[Na] [mg/kg]	0.029	0.001	0.023	0.151	0.023	0.133	0.105	0.011	0.021
[Al] [mg/kg]	0.348	0.121	0.277	0.319	0.102	0.223	0.257	0.066	0.144
[K] [mg/kg]	-0.019	0	-0.005	0.171	0.029	0.128	0.203	0.041	0.187
[Ca] [mg/kg]	-0.236	0.056	-0.158	-0.206	0.042	-0.146	0.017	0	-0.023
[Mg] [mg/kg]	-0.227	0.051	-0.101	-0.233	0.054	-0.071	0.167	0.028	0.088
[PO] [mg/kg]	-0.098	0.01	0.068	-0.07	0.005	0.049	-0.062	0.004	-0.133
[N] [mg/kg]	0.196	0.038	0.198	0.554	0.307	0.393	0.138	0.019	0.081
[C]:[N]	0.064	0.004	0.013	0.56	0.314	0.423	-0.44	0.193	-0.276
[C] [mg/kg]	0.171	0.029	0.175	0.638	0.406	0.45	0.013	0	-0.019
pH	-0.175	0.031	-0.105	-0.597	0.356	-0.521	0.245	0.06	0.146
electrical conductivity [μS/cm]	0.119	0.014	0.148	0.589	0.347	0.417	0.078	0.006	0
CEC	0.05	0.003	0.11	0.109	0.012	0.14	0.292	0.085	0.188
[Ca]:[Al]	-0.103	0.011	-0.194	-0.115	0.013	-0.203	0.042	0.002	-0.023
[Mg]:[Al]	-0.138	0.019	-0.206	-0.139	0.019	-0.182	0.08	0.006	-0.019
Drillable Soil Depth [m]	-0.049	0.002	0.349	0.177	0.031	0.152	0.094	0.009	0.079
kf	-0.156	0.024	-0.119	-0.228	0.052	-0.161	-0.057	0.003	-0.002
Stonecontent [%]	-0.246	0.06	-0.254	-0.172	0.03	-0.162	-0.217	0.047	0.005
Topographical Wettness Index	-0.11	0.012	-0.055	0.336	0.113	0.214	-0.152	0.023	-0.004

Table 4.3: Pearson and Kendall Correlations of the independent variables with Ordination Axes after Principal Coordinates Analysis.

The variable giving the clearest picture has already been used to provide a first overview of the results. The position on the watershed seems to be a good reference of species composition and integrates, to some extent, geology and precipitation.

Although the r^2 values for the correlation of precipitation with the axes are not particularly high (Tab. 4.3), it can be seen from Figure 4.17 that, on average, the samples on the Congo side receive higher precipitation than the samples positioned on the Nile-side. The low yet informative correlations with said axes thus allow for an according inference. As with Polar Ordination before, an explanation to the higher similarities of the Ruzizi and Gishwati samples to the Nile side samples cannot be based on this factor. The same statement can be made for the Gahurizo samples.

Despite the linear correlation being markedly increased, it is obvious that elevation a.s.l. is not the sole controlling impact variable (Fig. 4.18). The overall elevated altitude on the Nile side as compared to the Congo side is apparent with this analysis as well.

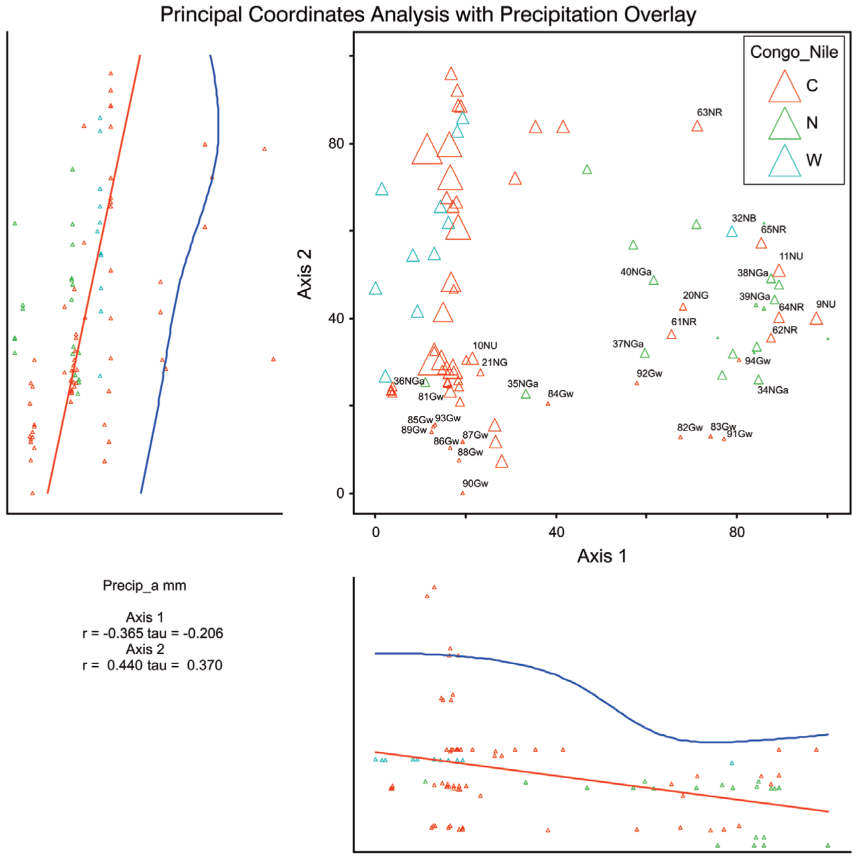


Figure 4.17: Scatterplot of the samples resulting from PCoA with mean annual precipitation overlay. The position on the watershed was used as a grouping variable.

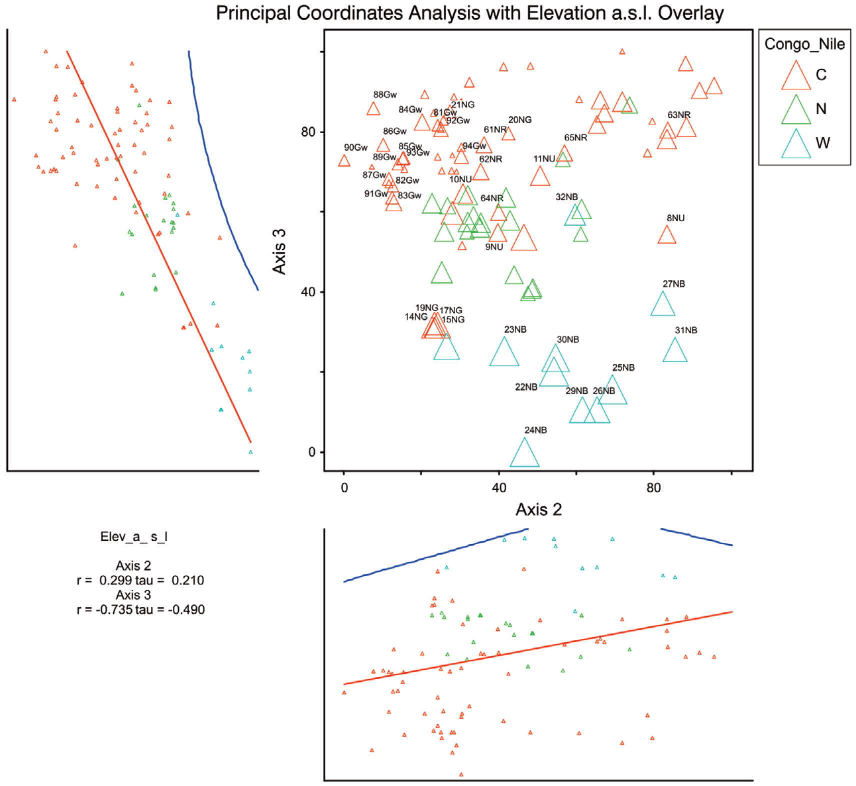


Figure 4.18: Scatterplot of the samples resulting from PCoA with elevation a.s.l. overlay. The position on the watershed was used as a grouping variable.

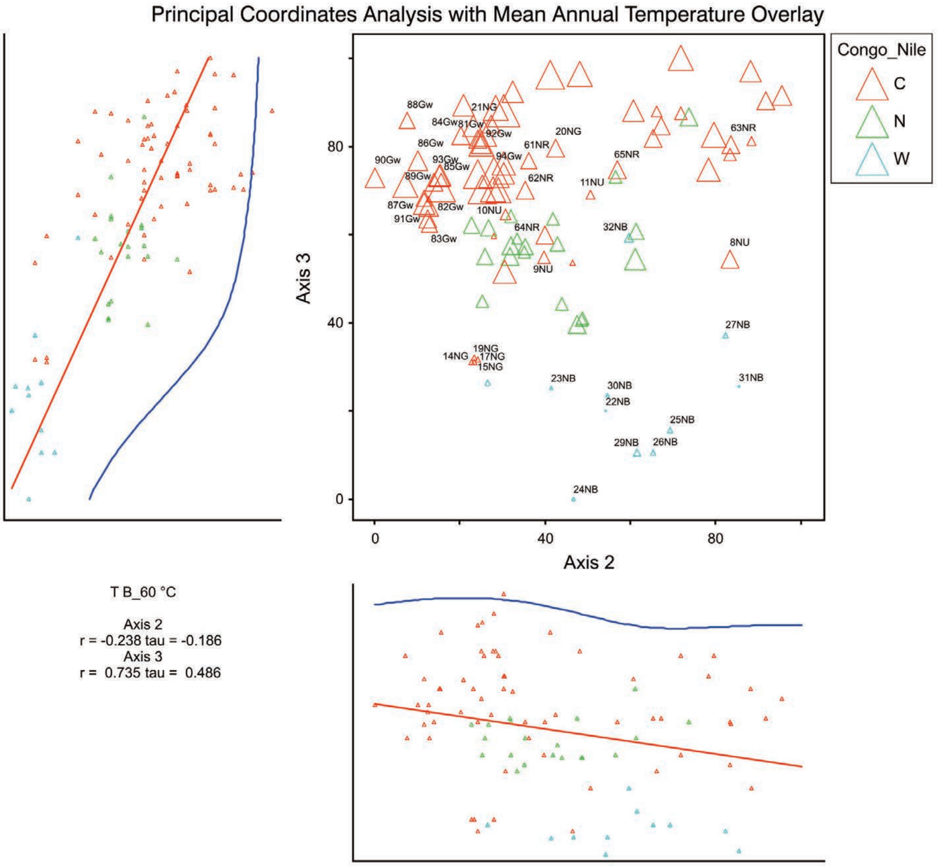


Figure 4.19: Scatterplot of the samples resulting from PCoA with mean annual temperature overlay. The position on the watershed was used as a grouping variable.

When overlaying temperature on the scatterplot and showing axes two and three jointly, it seems that the mean annual temperatures are somewhat higher on the Congo side (Fig. 4.19). This result, of course, stems from the negative correlation between altitude and temperature, which can be taken from Annex 5. Although, the promising correlation coefficients of both environmental factors have to be relativised due to the almost linear negative correlation between them, it remains to be seen if all of the impacts of temperature are integrated by elevation a.s.l. At least it does not seem to be a sufficient enough explanation for the separation of plot 16_{NG} from the rest of the samples on Mt Muzimu. From the plots, it could also be seen that the separation of the Ruzizi and Gishwati samples from the other Congo-side-samples is somewhat lessened along axis two and three.

Not as clear cut, though still influential, the distance to the forest margin has some impact on species composition as well (Fig. 4.20). Axes two and three exhibit the greatest correlations. At the same time, attention should be paid to the fact that, for the sites on Mt Bigugu, the vertical component outweighs the horizontal distance. As a pointer in this respect, the placement of the samples from Mt Muzimu, positioned in close proximity to sample 28_{NB}, might be compared. Along axes two and three, the separation of the Gishwati samples seems minimal, and new insights were, thus, not gained. When observing the samples from Gisakura (76-79_{NGk}), it becomes apparent that still other environmental variables are at work here.

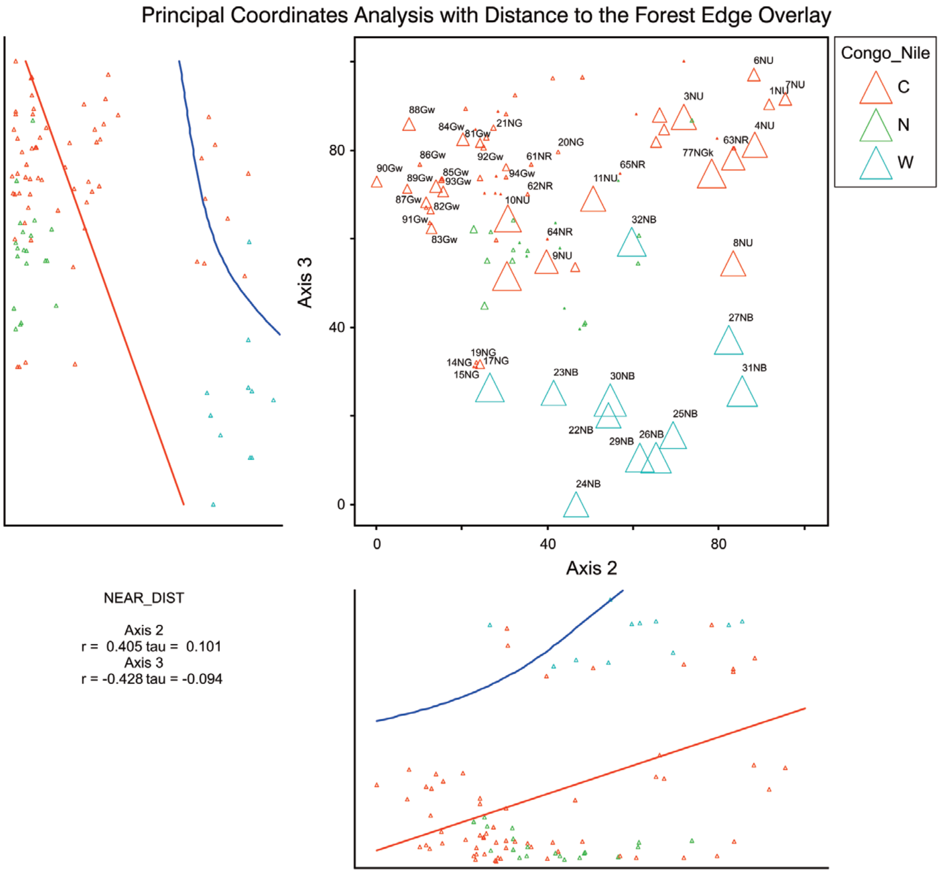
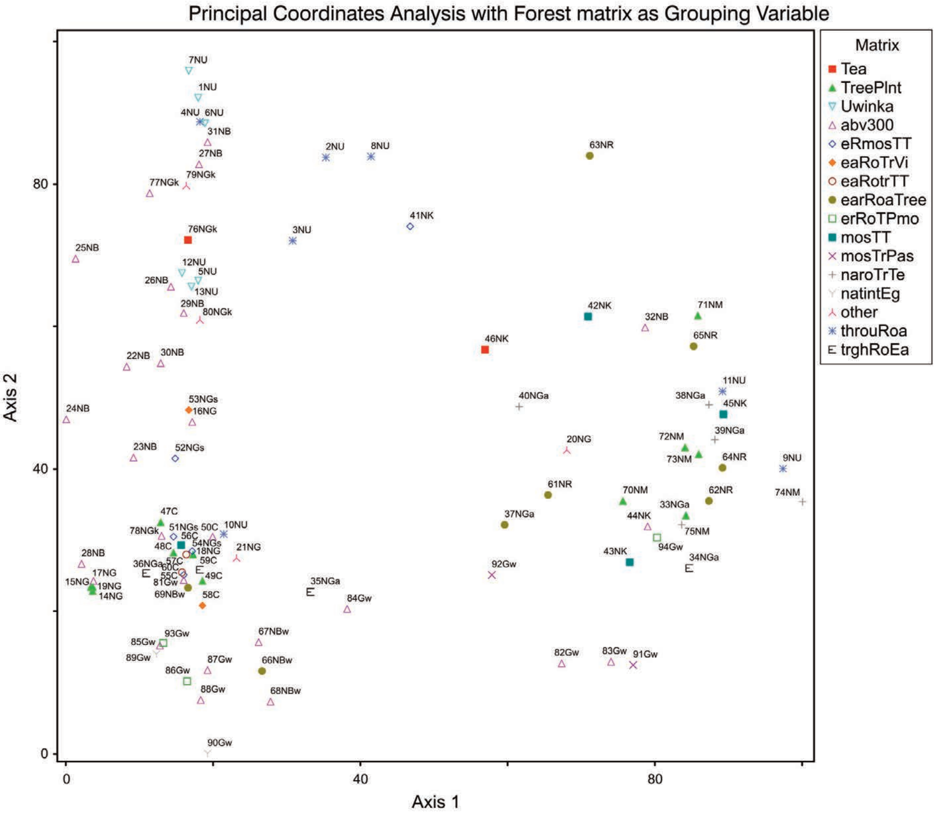


Figure 4.20: Scatterplot of the samples resulting from PCoA with distance to the forest edge overlay. The position on the watershed was used as a grouping variable.

Figure 4.21: Scatterplot resulting from PCoA. Using the forest matrix as group indicator.



The picture does not become clearer when utilising the forest matrix as a grouping variable. Though many of the sites that have a distance from the forest margin larger than 300 metres (LAURANCE ET AL., 1998) are grouped together and are arranged along the third axis, it is conspicuous that most of the sites in close proximity to each other are the sites positioned on Mt Bigugu and around the ranger station at Uwinka, respectively (Fig. 4.21). Elevation a.s.l. has a decisive impact on ordination as well (see above). As expected, the grouping of the sites is pertains to the area around the ranger station rather than it being in reference to the matrix.

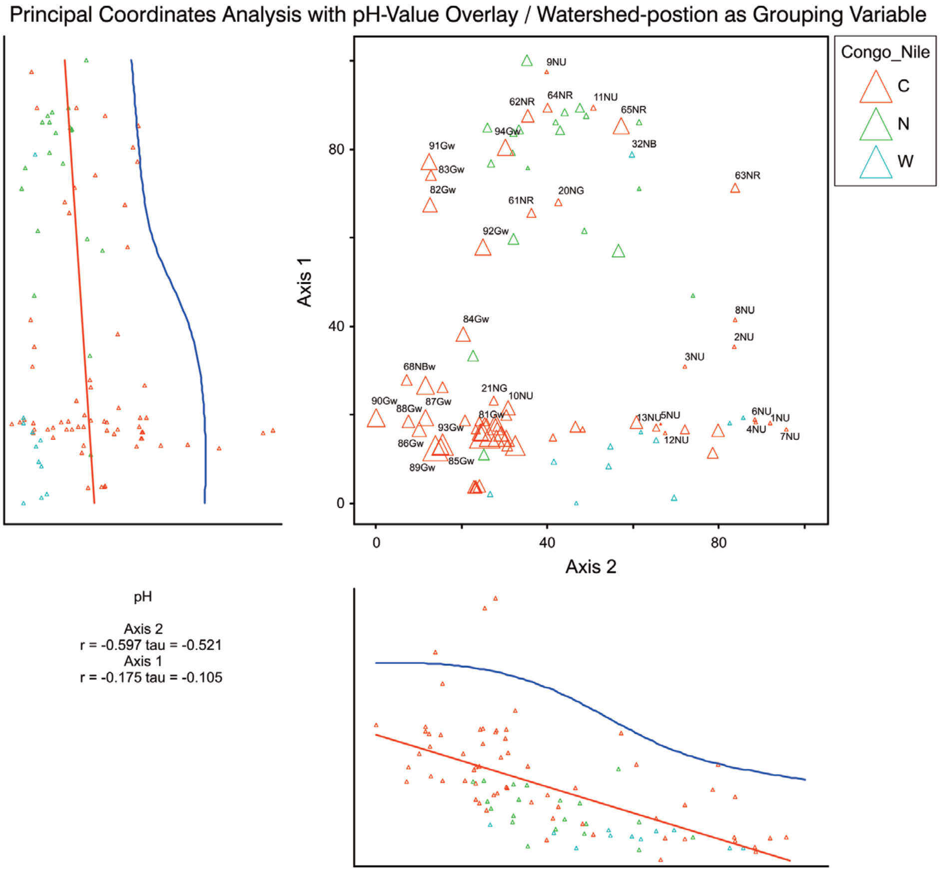


Figure 4.22: Scatterplot resulting from PCoA with a pH-value overlay. Using the position on the watershed as grouping variable. The size of the symbols indicates the magnitude of the pH-value. See captions for Figure 4.5 for interpretation.

Axis two has an elevated negative correlation to the pH-value, that, on average, when plotting axes one and two against each other, seems to be slightly higher on the Congo side of the watershed and reaches some of its lowest values on Mt Bigugu and around Uwinka. The reason for the separation of the Ruzizi and the two Uwinka samples along axis two might find a partial explanation here. For the separated Gishwati samples, no further information could be gained (Fig. 4.22).

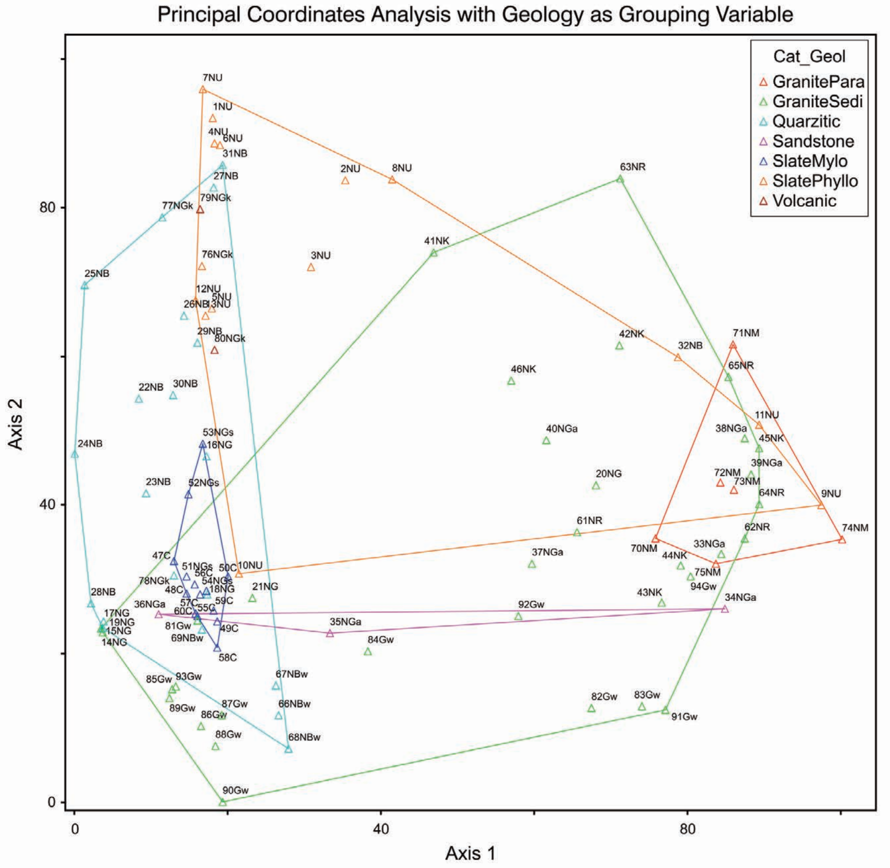


Figure 4.23: Scatterplot resulting from PCoA. The geology was used as a grouping variable and convex hulls were employed to mark the groups.

The impact of the geology can be taken from Figure 4.23. The samples from Cyamudongo and Gasumo have been positioned quite close on axes one and two and show only moderate dispersion on axis three. Since all are situated on slate with quarzitic micaschist components, which also contains mylonites, an inference to a likely impact might be made. The situation for the samples from Musebeya is comparable. In addition an explanation for the separation of the Gishwati and Ruzizi sites cannot be found here. The same is valid for samples 9_{NU} and 11_{NU}. Only sample 32_{NB}, which is situated on slate with micaschist and phyllonite components, exhibits a further distinctive feature. Still, it is positioned quite far from samples with the same geology. Although spread out along axis two, the samples from Bweyeye, Gisakura and Mt Bigugu are positioned somewhat close on axis one. With some exemptions from Gisakura, all of them are situated on schistous quartzite and meta quarzite complexes with a schistous deposit. For the samples from Gahurizo, the solution to the dispersion may be a bit more sizable, at least along axis two.

The paragraph above directly leads to the conclusion of the chapter on Principal Coordinates Analysis. Here, we will take a look at some bi-plots (Figs. 4.24). Not much different from figures 4.15 A to E, the r^2 cut-off value of the independent variables has been set to 0.09, and the variables thus depicted are: distance to the forest margin, pH, precipitation, EC [μS], [N], [C], [C]:[N], TWI and [Al] when plotting axis one and two in the same diagram. For axis one and three, the mean annual temperature and altitude display their common behaviour, and the distance to the forest margin permits some inference as to its impacts on species composition as well. Along axis three, the [C]:[N] ratio and the insolation display some minor impacts. For [Al], the same is true for both axes. Axis two and three, when plotted against each other, once again show the variables mentioned.

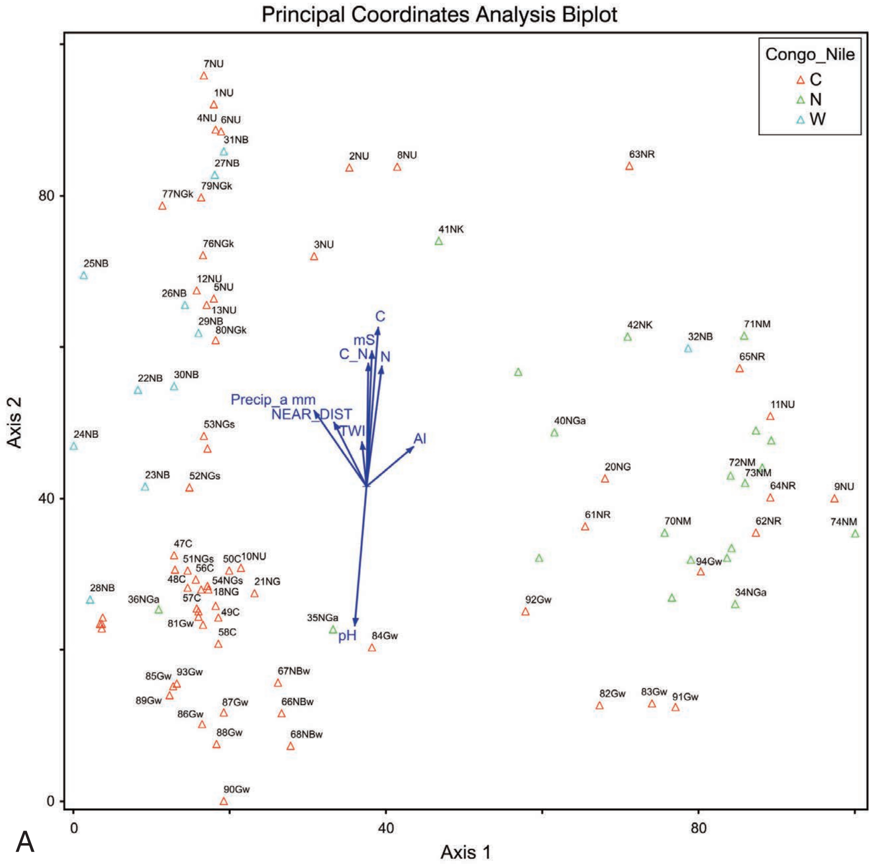


Figure 4.24: panes A to F; Biplot of the samples and the independent variables. Panes C and E show an overlay of the distance to the forest edge. The size of the symbols indicates the magnitude of the distance. Pane F includes an overlay with the pH-value. A correlation with the altitude a.s.l. is clearly visible. For further interpretation see the captions to Figure 4.5.

From the plot of axis one against axis two, still no explanation arises as to the bi-modal ordination along axis one (Fig. 4.23 A). The only variables showing any correlation worth mentioning are mean annual precipitation and the [Al]. The respective r^2 values of 0.13 and 0.12 are, firstly, very low and secondly, not adequate for inferences to be based on. The separation of the Gahurizo samples along axis one remains elusive. For the segregated Gishwati samples, it can be said that most of the samples with an elevated [Al] are affected. Two of the samples from Gishwati Forest which also exhibit higher Al contents, are not separated. Though the [Ca] only has a minor correlation to axis one, it may be mentioned at this point that [Ca] is particularly low for the Gishwati samples at hand (not shown).

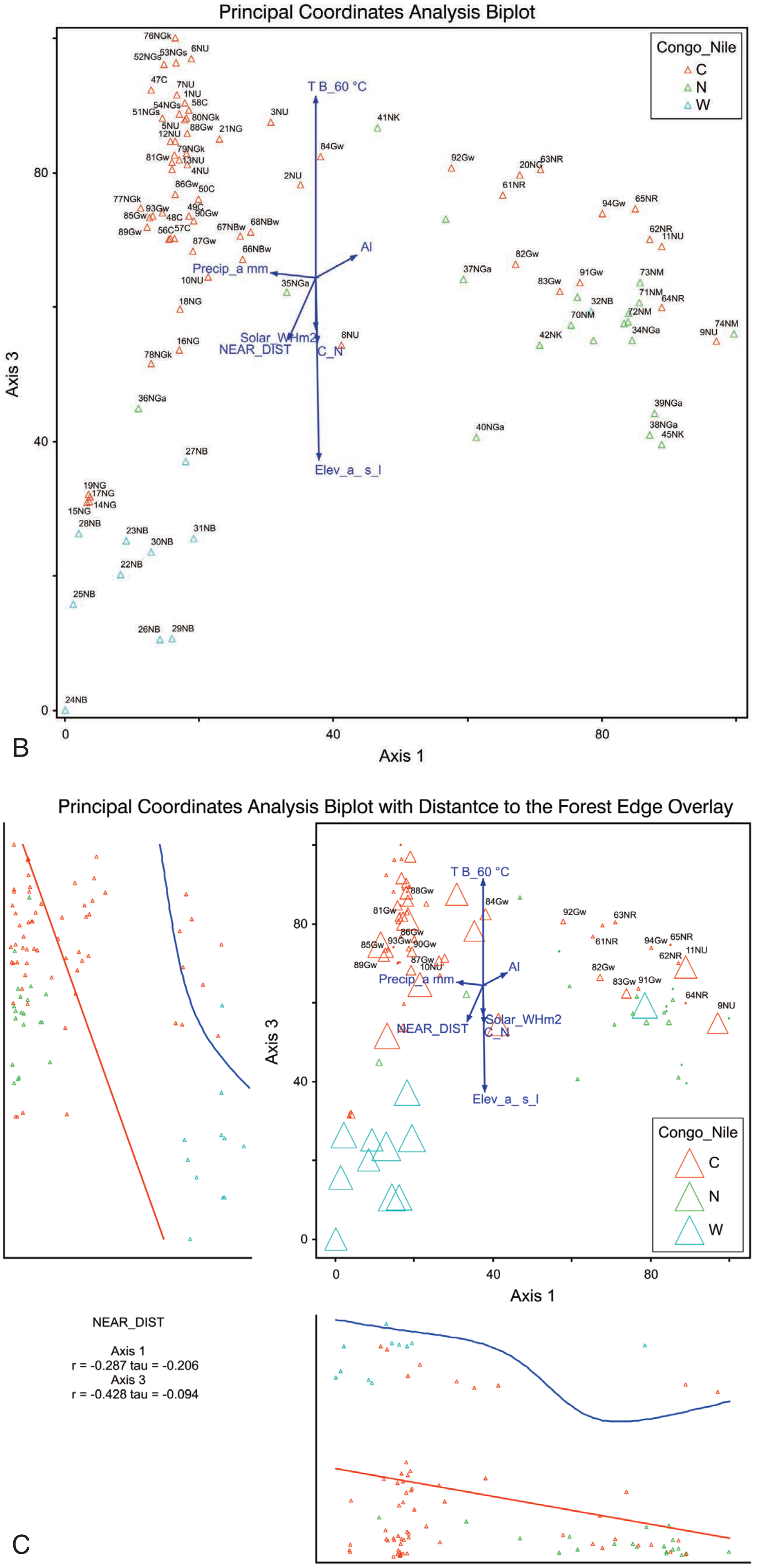
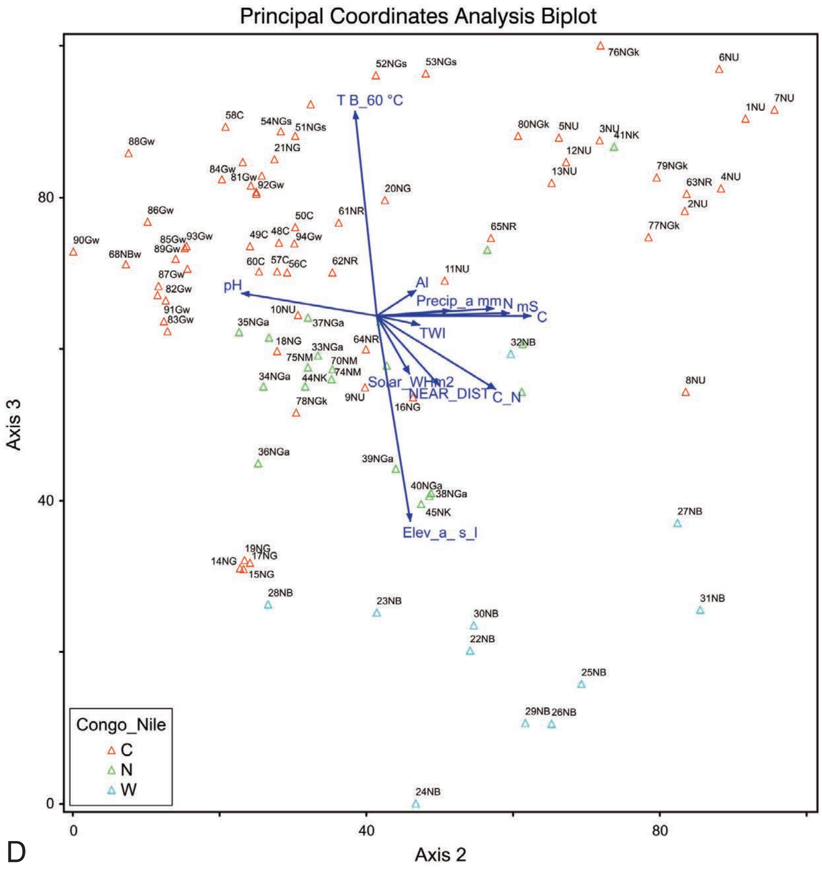
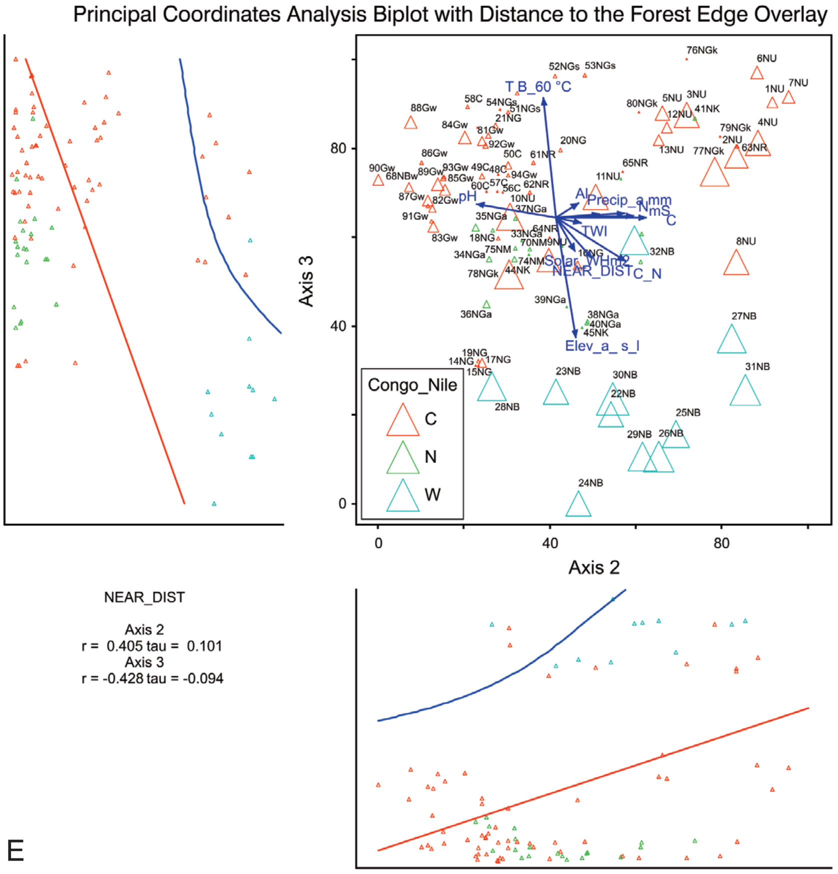


Figure 4.24: panes B to C; for further information see above and in the text.

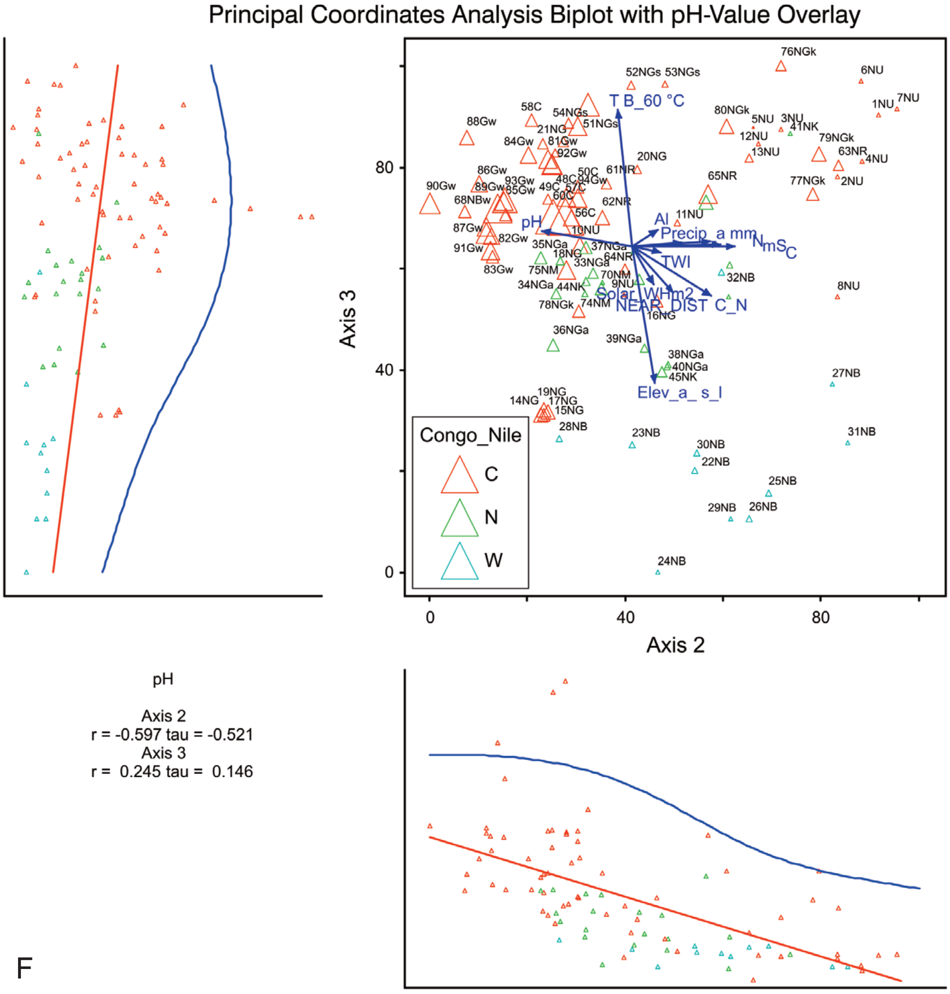


D



E

Figure 4.24: panes D to E; for further information see above and in the text.



Principal Coordinates Analysis Biplot with pH-Value Overlay

Figure 4.24: pane F; For further information, see above and in the text.

The plot depicting axes one and three still shows the somewhat bi-modal distribution along axis one (Fig. 4.23 B). Along axis three, the polarity of elevation and temperature leads to a separation of the samples along an elevational, i.e., temperature gradient. Again, the distance from the forest margin has its most considerable correlation with axis three, and the samples are arranged accordingly. The trend is superimposed by the elevational gradient, as has been stated above. Still, an inference as to the situation of the Nyungwe, Ruzizi and Gishwati samples on the right-hand side of axis one cannot be made.

The scatterplot of axis two and axis three reveals the same relations between EC, [C], [N], [C]:[N], [Al], pH and elevation as Polar Ordination did (Fig. 4.23 D). The same conclusions are thus derived: With an increasing elevation and, especially, a decreasing pH, humification prevails and organic material accumulates. It is within these, though acidic substances, that electrical conductivity is increased as opposed to warmer and more alkaline conditions. The largest correlation value of mean annual precipitation can be found with axis two. It is also with axis two that pH, TWI and electrical conductivity have their largest correlation values. The increasing humidity, as indicated by the vectors displaying precipitation and TWI, respectively, fosters acid conditions and hampers mineralisation.

With the topographical wetness index, some correlations to other variables have to be considered. Although inclination does not seem to have an impact on species composition, it is correlated negatively to the TWI at a medium level. Insolation, which has an $r^2 =$

0.15 to the third axis, is strongly positively correlated to TWI. Since it is negatively correlated to inclination as well, the relation between TWI and insolation seems rather spurious.

In conjunction with Fig. 4.24 F, it can be seen that the sites at medium altitudes separated in the upper right corner do have a lower pH value. This value sets them apart from the sites on the upper left part of the plot, while altitude separates them from the sites on Mt Bigugu and Mt Muzimu, respectively. Though small, the impact of the distance from the forest margin still separates the sites in the lower right triangle of the plot from the ones in the upper left with only a few, and close to the diagonal, exemptions (Figs. 4.24 C and E).

4.1.3 Summary of the Indirect Ordinations

Though the scatter plots differ to quite some extent, both extracted similar patterns. When taking a look at Figures 4.3 and 4.16, it becomes apparent that, though the improvements on the original method of Bray & Curtis (1957) have been used, ordination is still governed by the undue impact of the largest distances. Although the samples from the Congo side are still positioned quite close to each other in the lower left corner of plot 4.16, they are spread out more evenly and, thus, may give a better impression of the underlying gradient(s) and dissimilarities.

Both methods resulted in scatterplots showing the division between the Congo and the Nile side of the watershed while setting apart the samples from higher altitudes as well. The methods likewise showed that the separation between the respective side of the watershed might not be as clear cut as commonly supposed. Comparing Figures 4.3 and 4.16, there are some fundamental differences in the ordination of the samples from Mt Bigugu. The bulk of the samples from the Congo side, though more spread out by PCoA, are still ordinated along axis two by both techniques. The same is true for axis three in both approaches. When examining Figure 4.16, the distinction between either a bi-modal distribution along axis one or a horseshoe effect, even from a plot of axes one and three, proves to be of some effort. If in fact present, the bi-modal distribution along the first axis is much less pronounced with Polar Ordination (4.3). Either way, a gradient is intrinsic to the construction of axis one. If a horseshoe is indeed present, it stems from the Euclidean representation of the progressive change in the taxonomic composition of the samples along an environmental gradient (Legendre & Legendre, 1998, p. 466). Be that as it may, the gradient along axis one, i.e., the environmental factors responsible, could not be clarified to a full extent. The concentration of aluminium and mean annual precipitation are correlated to axis one by PCoA but do not suffice as an explanation for the ordination. With Polar Ordination, the distance to the forest margin may explain about 18% of the variation, while the stone content of the soil adds another 14% and [Al], a further 13%. Yet, the stone content is generally low and, thus, bears only little explanatory value. When it comes to mean annual precipitation, both account for the differences and, both fail to explain the separation of the Gishwati, Uwinka and Ruzizi samples from the rest of the Congo-side-samples along axis one.

The linear relations computed on the basis of PCoA are generally higher, and so is the one for elevation along axis three. Still, both methods have elucidated the elevational gradient and have shown the major impact of altitude. The same holds true for the temperature.

The methods utilised gave similar results concerning the distance to the forest margin. Though minor, the impact is not to be neglected. Given the circumstances that the survey could not be carried out in the intended way, the result is quite interesting. When it comes to geology, the separation among the samples is more apparent with Polar Ordination (Figs. 4.8, 4.23). Though of some explanatory value, it seems possible that other processes overlay the impact on soil properties. The option to use subjective endpoints for the axes to be constructed using Polar Ordination, gave results which are more similar to the correlations resulting from PCoA. The partially subjective approaches generally confirmed the presence and importance of the best-known differentiating factors. The bi-plots largely gave the same outcomes with both methods. The main differences were the impacts of the stone content, [Mg] and [Ca] within Polar Ordination and TWI as well as insolation as found by PCoA.

As has been stated above, the impact on soil conditions stems from a variety of factors. The conditions associated with montane tropical rainforest require harsher environmental conditions and lower litter decay rates (see Vareschi, 1980). It is no wonder that the accumulation of organic material is facilitated under acidic conditions and with a still decreasing pH in cold temperatures since bacterial activity is already decreased under acidic conditions and fungal activity, which copes better in low pH than bacteria, is slowed down by reduced temperatures (Vareschi, 1980; McCauley et al., 2017).

In summary, what we have learned so far is not surprising. None of the environmental factors alone determines species composition. It is a suite of independent variables which jointly cause shifts in species composition between sample sites. Independence gives the cue to another phenomenon; environmental variables may be independent to a certain extent but not entirely. First, there are relations amongst them, and second, some parameters are impacted by vegetation. Thus, interpretation may be done in careful respect of the interdependencies between elevation a.s.l., temperature, [C]:[N] and pH.

Therefore, inference has it that none of the correlated impact factors acts upon species composition to the extent that could be assumed from the correlation coefficients. Yet, within both methods, impacts are dealt with as if independent from one another. As we have seen in the discussion about soil properties, interactions can be hard to elucidate. A further characteristic should be kept in mind as well; the correlation factors only consider the linear parts of the correlations.

It was stated above that, according to Podani & Miklos (2002), who followed Kendall (1971), a relationship in form of a parabola will result in an entirely linear arrangement in an ordination using the Manhattan distance. These results are in accordance with the ones obtained in the analysis at hand (not shown) and thus concurs with the high percentages of variation left for interpretation on the first axis in our ordination as well. Another option to identify a parabolic relation is to compute the correlation between the first axis and species richness (Podani & Miklos, 2002). For the work at hand, no strong correlation has been found (result not shown). With a few exemptions the communities construed in section 3 have been recovered rather well by both of the ordination methods (Figs. 4.25 A to C and 4.26 A to C). The same is the case with regard to the supra-communities (Fig. 4.25 D to F and 4.26 D to F).

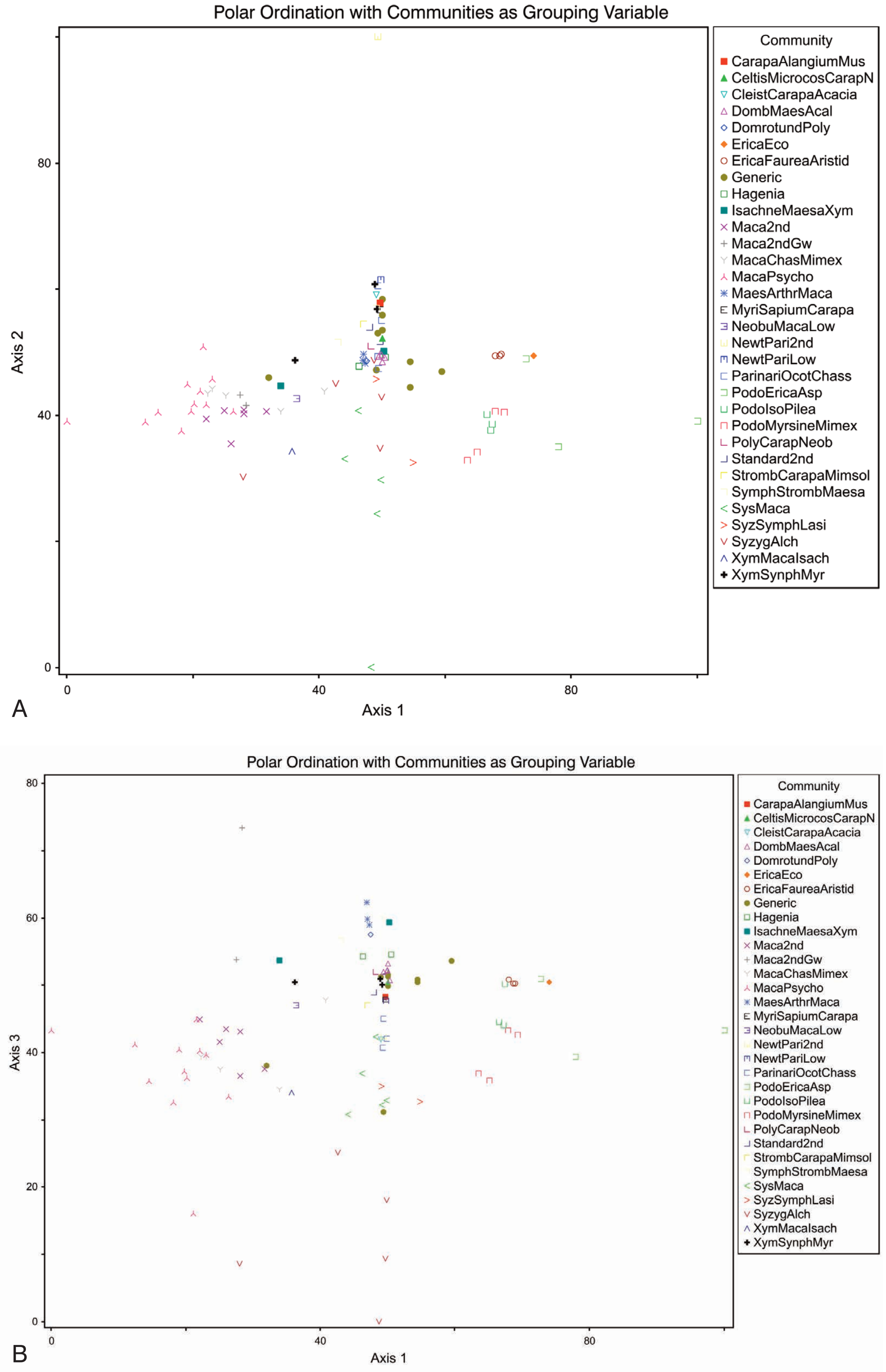
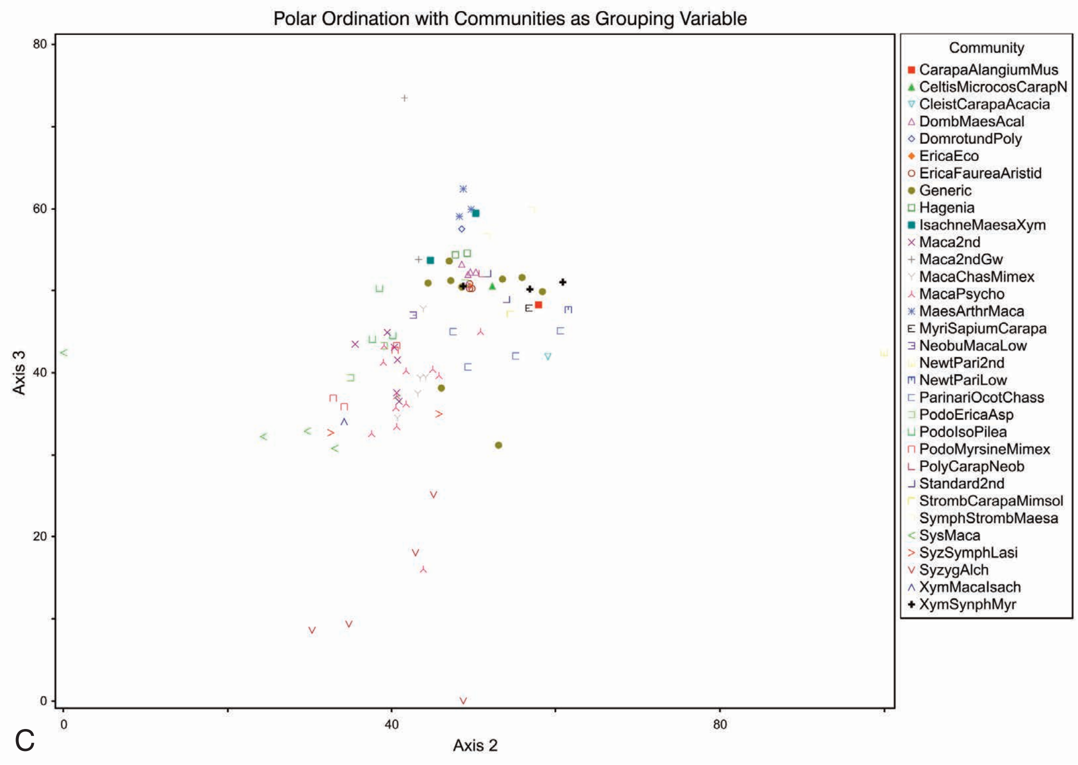


Figure 4.25: panes A and B; The axes endpoints of the Scatterplot were chosen by variance regression during Polar Ordination. The City Block projection is used. The category generic comprises singleton communities only. The aggregation was necessary due to the limitation of the number of groups in PC-Ord.



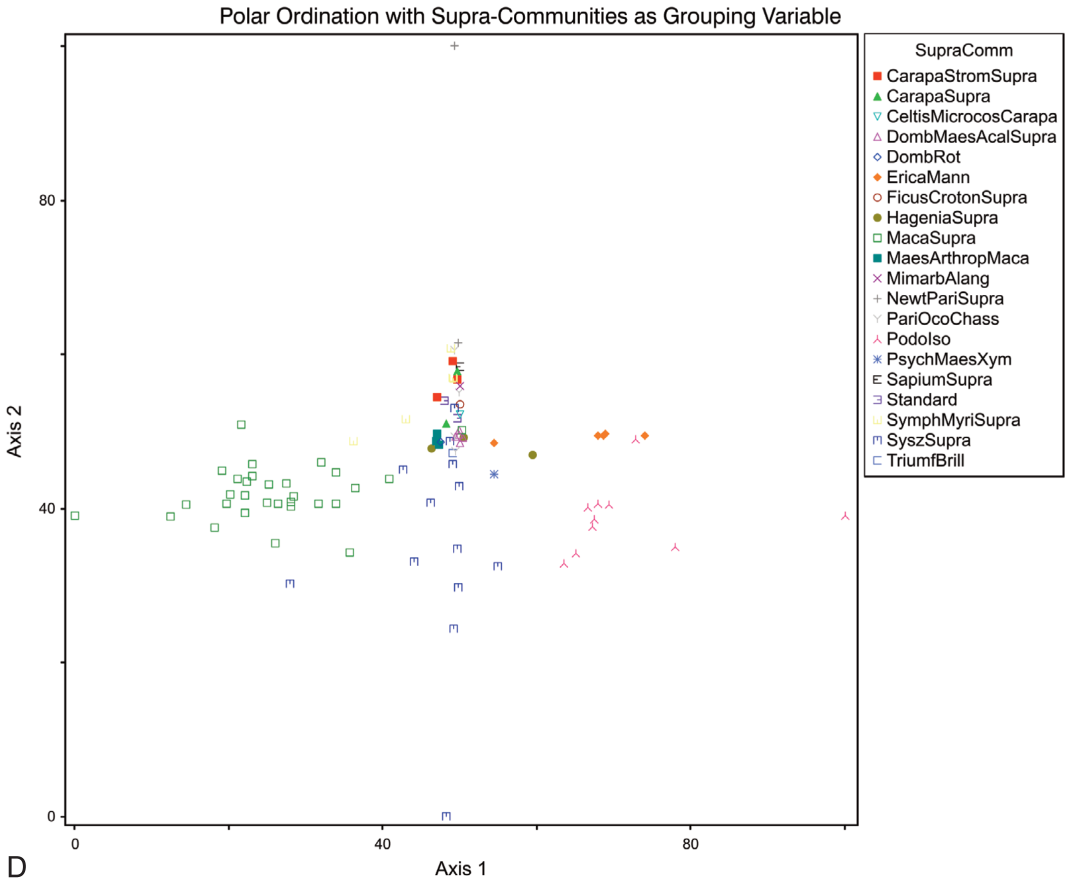


Figure 4.25: panes C and D; Scatterplot of the samples in City Block projection. The category generic comprises singleton communities only. The aggregation was necessary due to the limitation of the number of groups in PC-Ord.

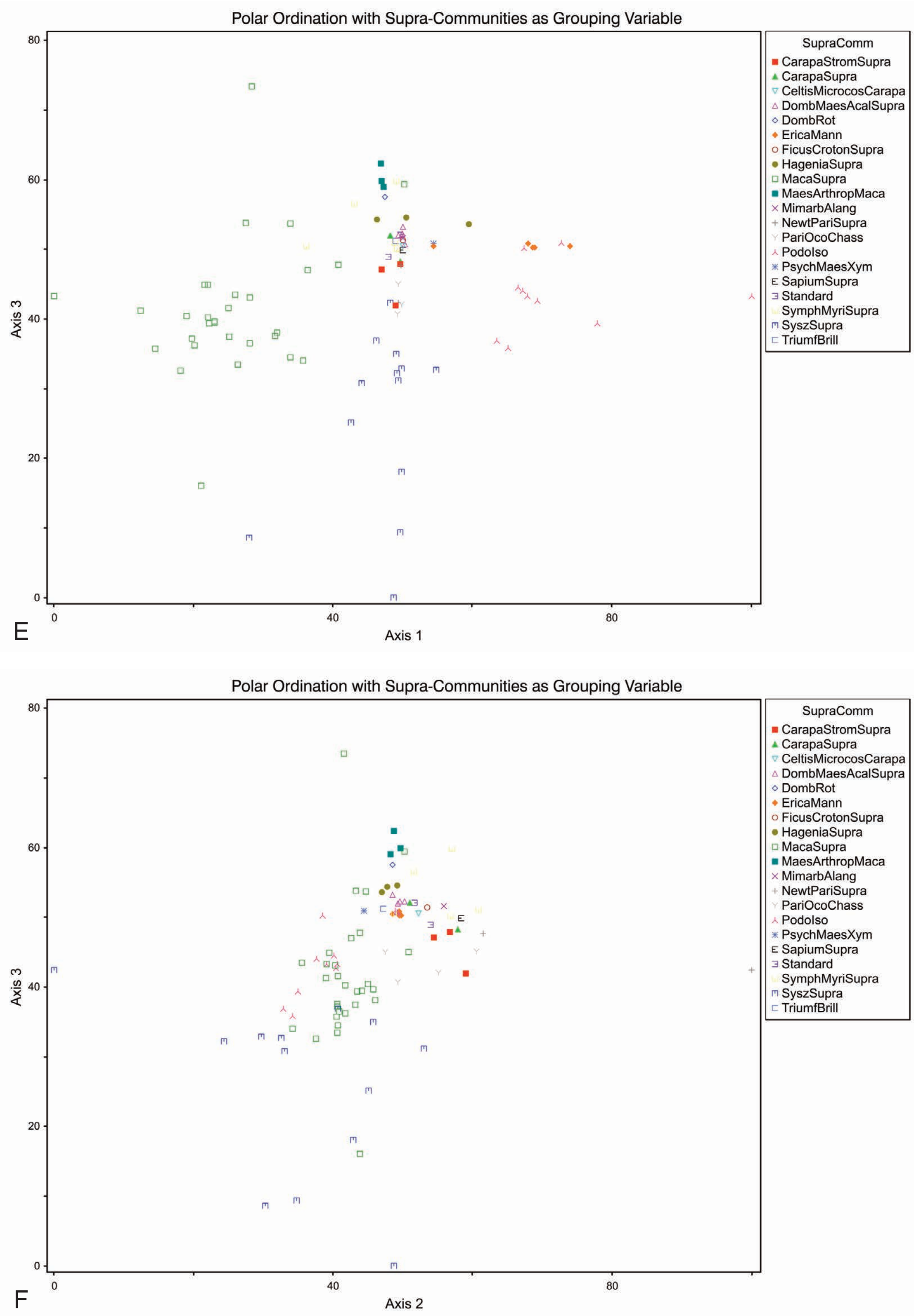


Figure 4.25: panes E and F; Scatterplot of the samples in City Block projection. Like the communities, the supra-communities are best recovered along axes one and three.

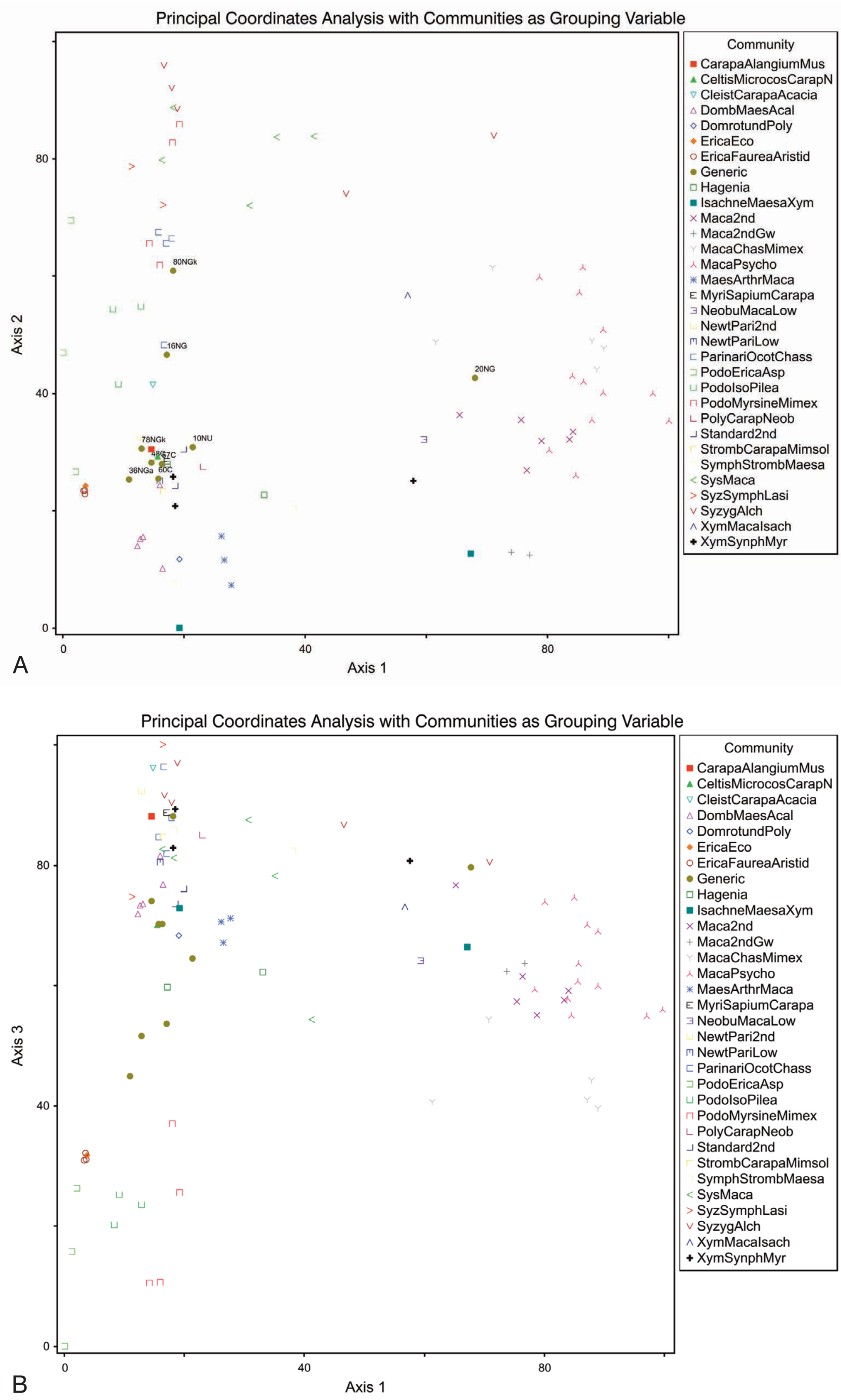


Figure 4.26: panes A and B; Scatterplot of the samples. The category generic comprises singleton communties only. The limitation of the number of groups in PC-Ord necessitated the aggregation.

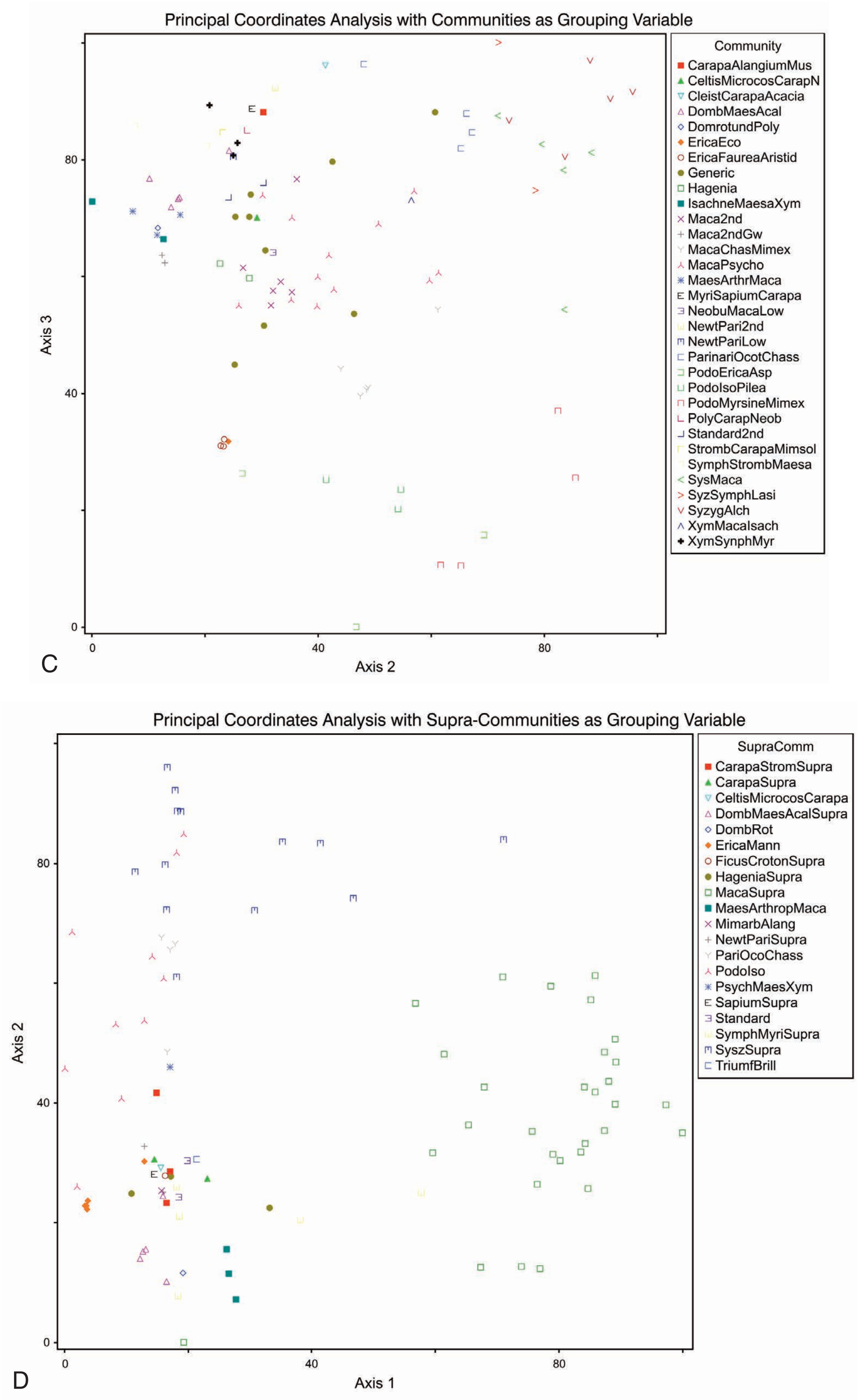


Figure 4.26: panes C and D; Scatterplot of the samples after PCoA. The supra-communities have been recovered slightly more accurate.

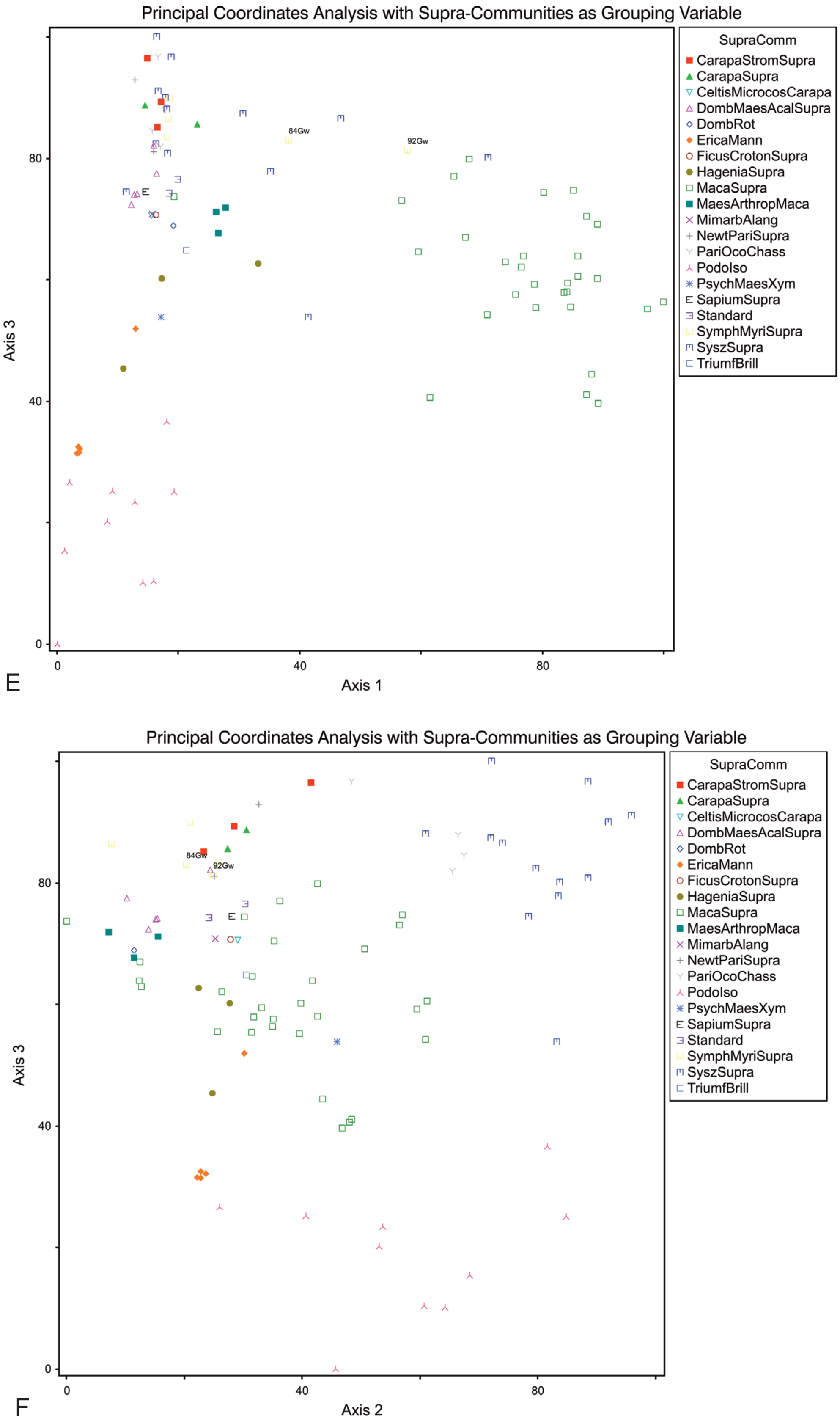


Figure 4.26: panes E and F; Scatterplot of the samples resulting from PCoA.

4.2 Constrained Ordination

In the previous sections, discontinuities in the vegetation have been sought after by means of classification approaches. Continuous gradients, i.e., the direction of the largest variations within species composition were searched for using unconstrained ordination. Since only a post hoc relation could be established between environmental predictors and species variation, a more direct quantitative approach will be taken now. Furthermore, both unconstrained ordination methods focused on the linear part of correlation. In the following, methods will be applied to accommodate the non-linear part of variation. To elucidate the intercorrelations among the independent variables, the partial versions of CCA and RDA were applied. So, which processes generate the spatial variation in community composition?

4.2.1 Preparative

The aim of the survey is to get results quickly, but certain requirements have to be met. Thus, a detrended correspondence analysis (DCA) was computed prior to any constrained analyses. From the results, it can be seen that along the first four axes 12.70% of the variation present in the response data are displayed. The gradient length given on each of the respective axes, since it is longer than four standard deviation units of species turnover (SD), exhibits clear unimodal responses (Tab. 4.4) (TER BRAAK & ŠMILAUER, 2012). The graph derived by DCA does not show an arch effect on either axis (Graph not shown). Now that a unimodal response has been confirmed by a unimodal model, a canonical correspondence analysis (CCA) can be executed.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.87	0.77	0.61	0.50
Explained variation (cumulative)	4.00	7.56	10.37	12.70
Gradient length	10.49	7.86	4.83	4.77

Table 4.4: DCA results. The gradient length is given in standard deviation units of species turnover (SD). The respective gradients along axes one and two are insinuating more than one species turnover. Axes three and four likewise exhibit more than one species turnover. The fraction of variance represented by the axes amounts to 12.70%.

4.2.2 Hierarchical Approach

Before turning towards the impact variables measured and collected, a quick look towards the explanatory potential of the forest identity, the position towards the watershed and the differences between the ranger stations is taken. Thus, a hierarchical approach was taken to test the variation among the forests compared to the variation within a forest. The same has been done for the variation at the rangerstation level. Again both approaches, the unimodal one based on CCA and the linear one based on RDA utilising Hellinger transformed data, have been used.

In order to describe the variation caused by forest membership alone, analyses constrained by forest membership have been carried out. Only one ranger station is in place in Cyamudongo and Gishwati, respectively, i.e., no real variation could be observed at this level. Thus, to give at least an impression, samples have been used directly and permutation has been unrestricted (pers. comm. ŠMILAUER). The variation thus explained by CCA amounts to 3.22%$_{adj}$ while tb-RDA attributed 5.57%$_{adj}$ explained variation to the differences arising from forest membership. Although the Euclidean distance is used in the graphs, the similarities among the samples are somewhat well depicted and reflect the discussions from paragraphs 3.2 and 3.3. The graphs stemming from tb-RDA separate the samples more clearly, largely differing inferences however are not possible (Figures: 4.27 and 4.28).

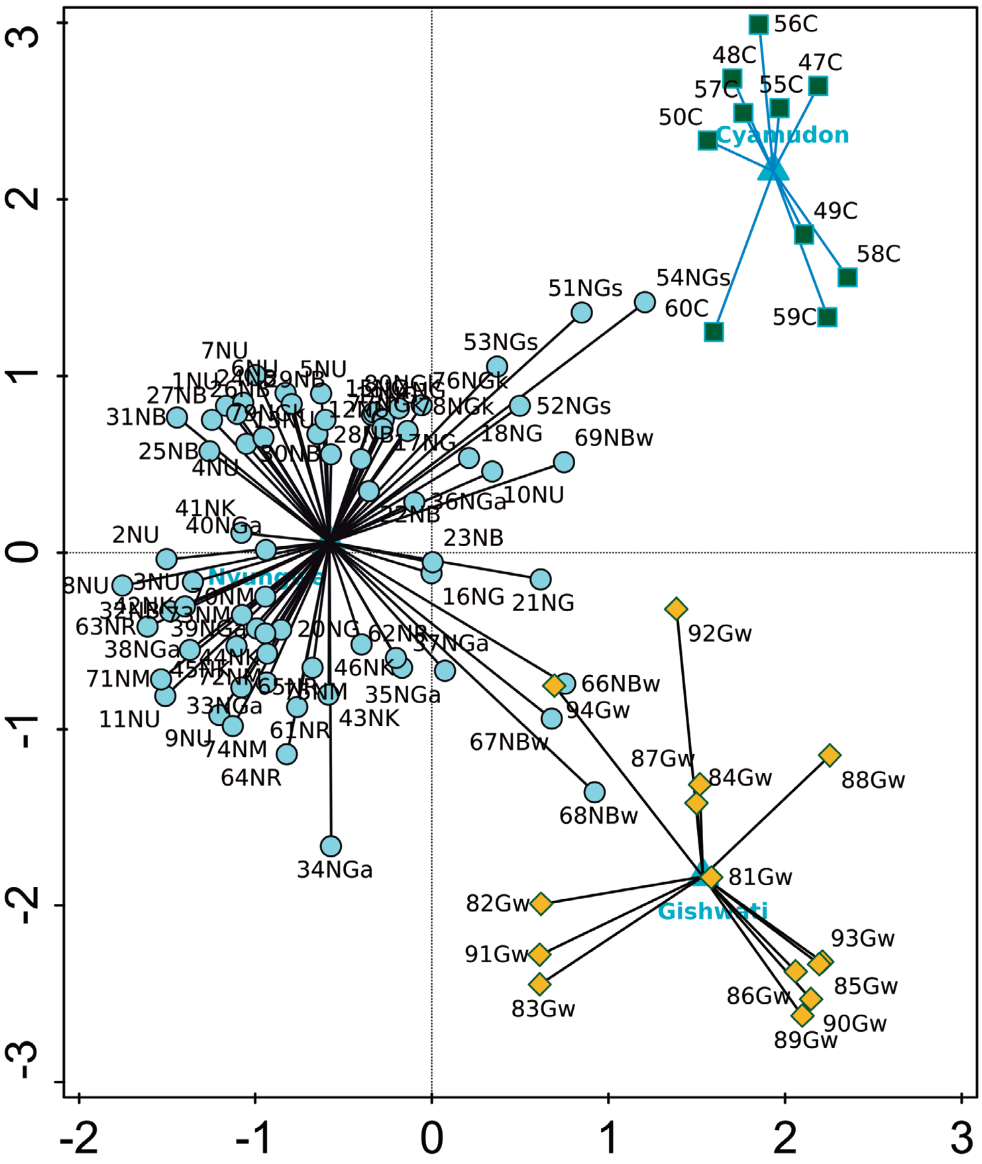


Figure 4.27: Star plot of the samples in relation to the forests resulting from tb-RDA. The light blue triangles at the the centre of each star represent the average relative species compostion of the individual samples. The distance between the environmental class symbols approximates their dissimilarity in species composition measured as the trunover distance in SD units. The distance of a sample symbol from an environmental variable class (forest symbol) can be seen as the dissimilarity between the relative species composition of that sample and the average relative species composition of the individual class. It can also be expressed as a prediction of the sample's membership in the class under consideration. The distance between the sample symbols estimates the dissimilarity of their species composition as the trunover distance in standard deviation units (Mahalanobis distance). The scaling of the plot is focused on the sample scores (Hill scaling).

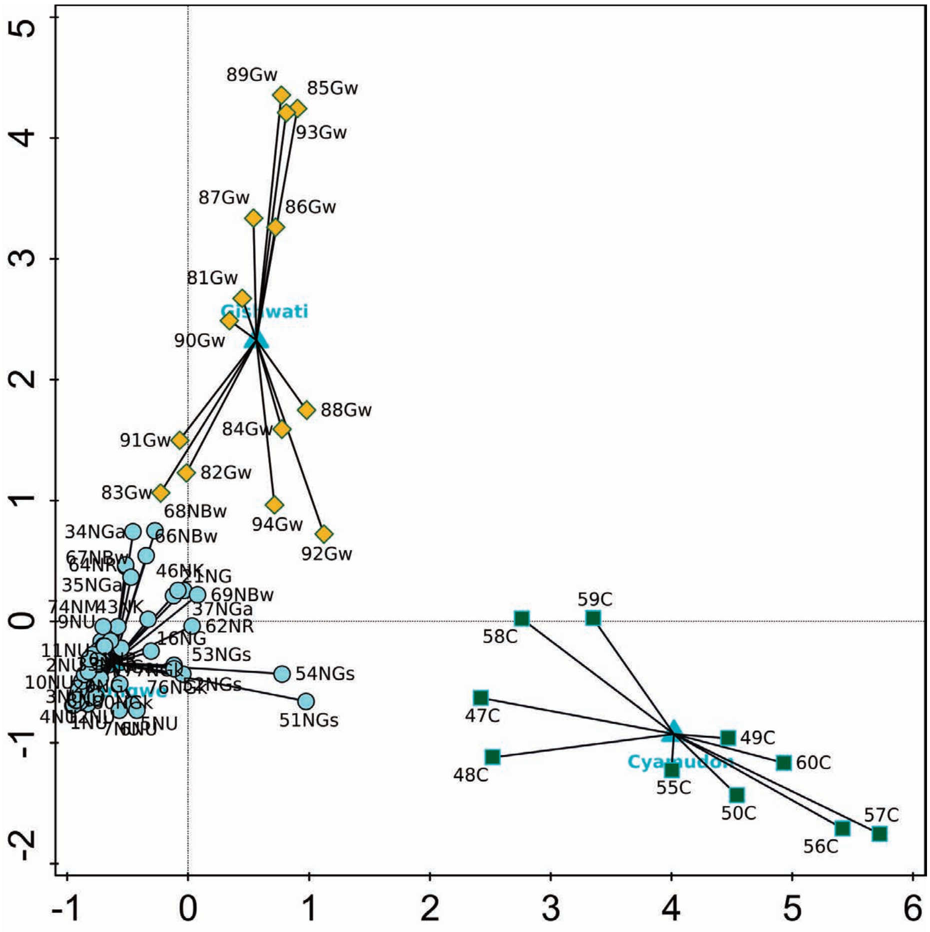


Figure 4.28: Star plot of the samples in relation to the forests resulting from CCA. Hill scaling was used to establish the axes. For further information see the captions of Fig. 4.27.

Since both Gishwati and Cyamudongo are situated completely on the Congo side of the watershed, a non-partial approach has been taken in the following analyses. Utilising the watershed position as the only explanatory variable resulted in an explained variation of 22.35% or 5.09%$_{adj}$ for CCA and in 26.07% or 9.64%$_{adj}$ for the tb-RDA path. For Nyungwe forest, here the position towards the watershed truly varies, separated analyses were carried out. The unimodal procedure resulted in an explained variation of 26.94% or 6.07%$_{adj}$. While the tb-RDA gave a variation explained of 34.59% or 15.90%$_{adj}$.

The graphical representations differ not very much among the analysis approaches. Both, illustrate the similarities between the ranger stations reasonably well. This statement holds true for the separate treatment of Nyungwe Forest (Figures 4.29-4.31).

All of the graphs lead to the same conclusions as the ordination and classification methods used before, the segregation between the sides of the watershed are not clear cut and some of the samples exhibit quite some similarities (Figures 4.29-4.31).

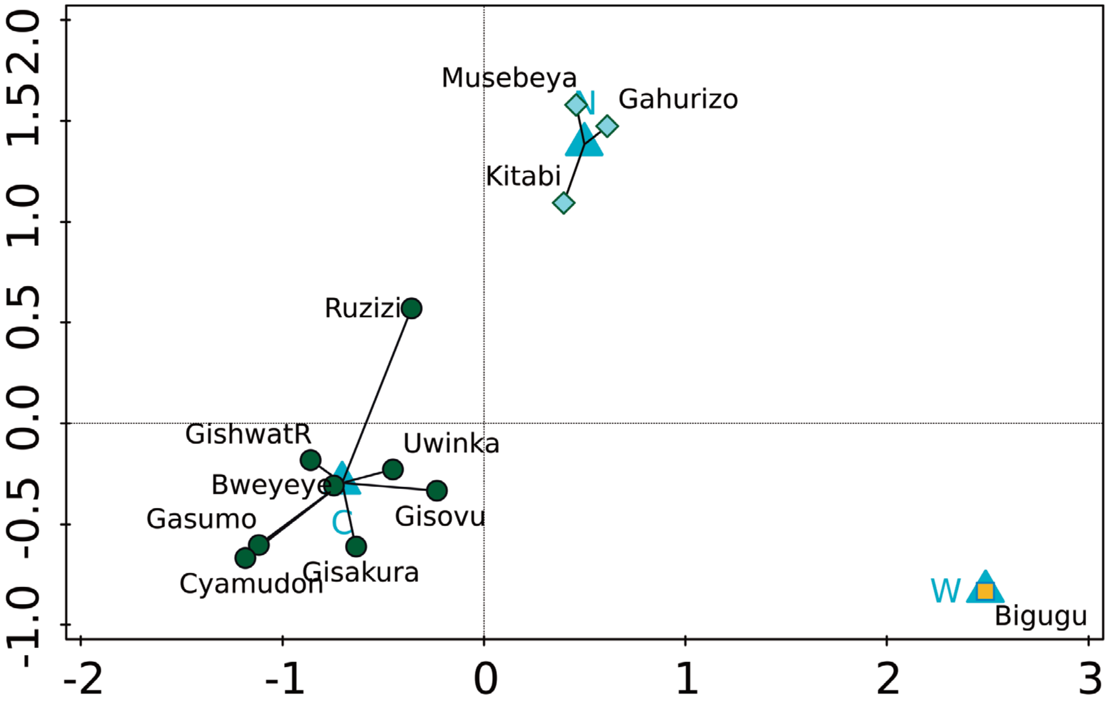


Figure 4.29: Star plot of the aggregated samples (ranger station level) in relation to the forests resulting from CCA. Interpretation is similar to Fig. 4.27. Here, the samples are aggregated at the level of the respective ranger station. Hence, the distances between symbols approximate the average dissimilarity between their species compositions as measured by the Mahalanobis distance, i.e., the turnover distance in SD units.

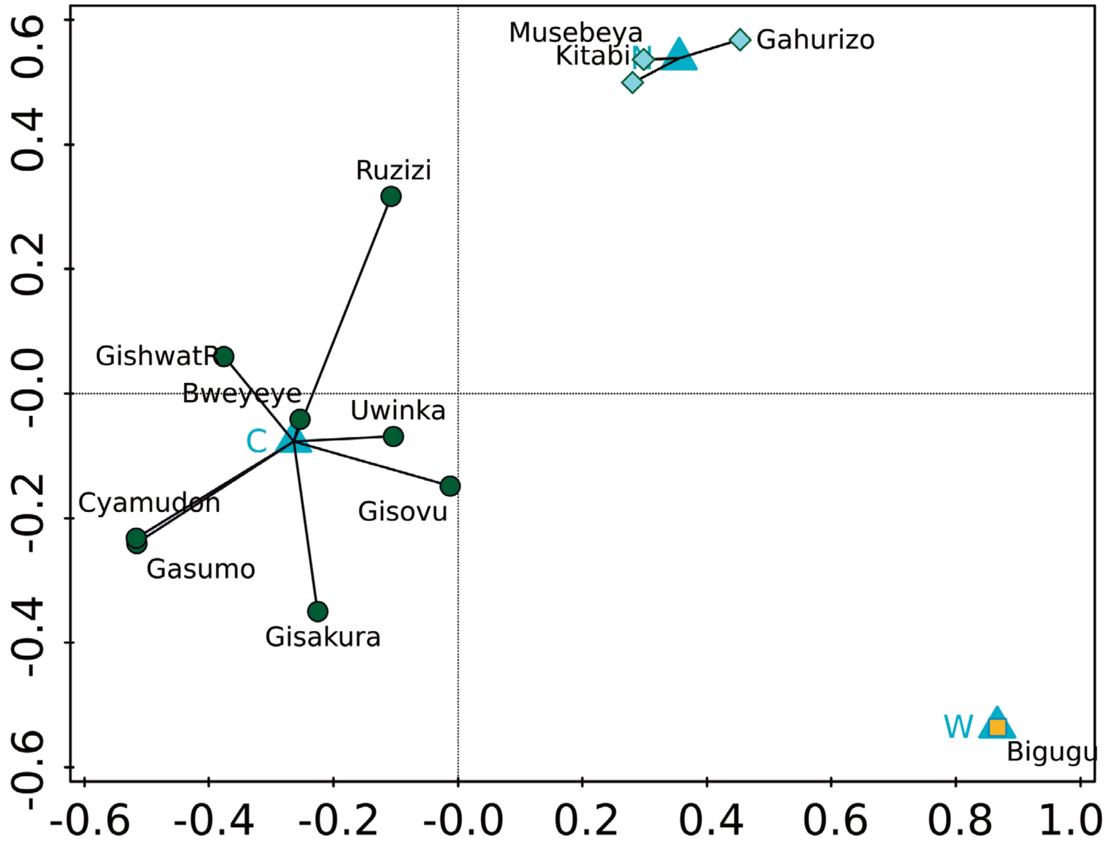


Figure 4.30: Star plot of the aggregated samples (ranger station level) in relation to the forests resulting from tb-RDA. For information on interpretation see captions of Fig. 4.29. Hill scaling was used to define the axes.

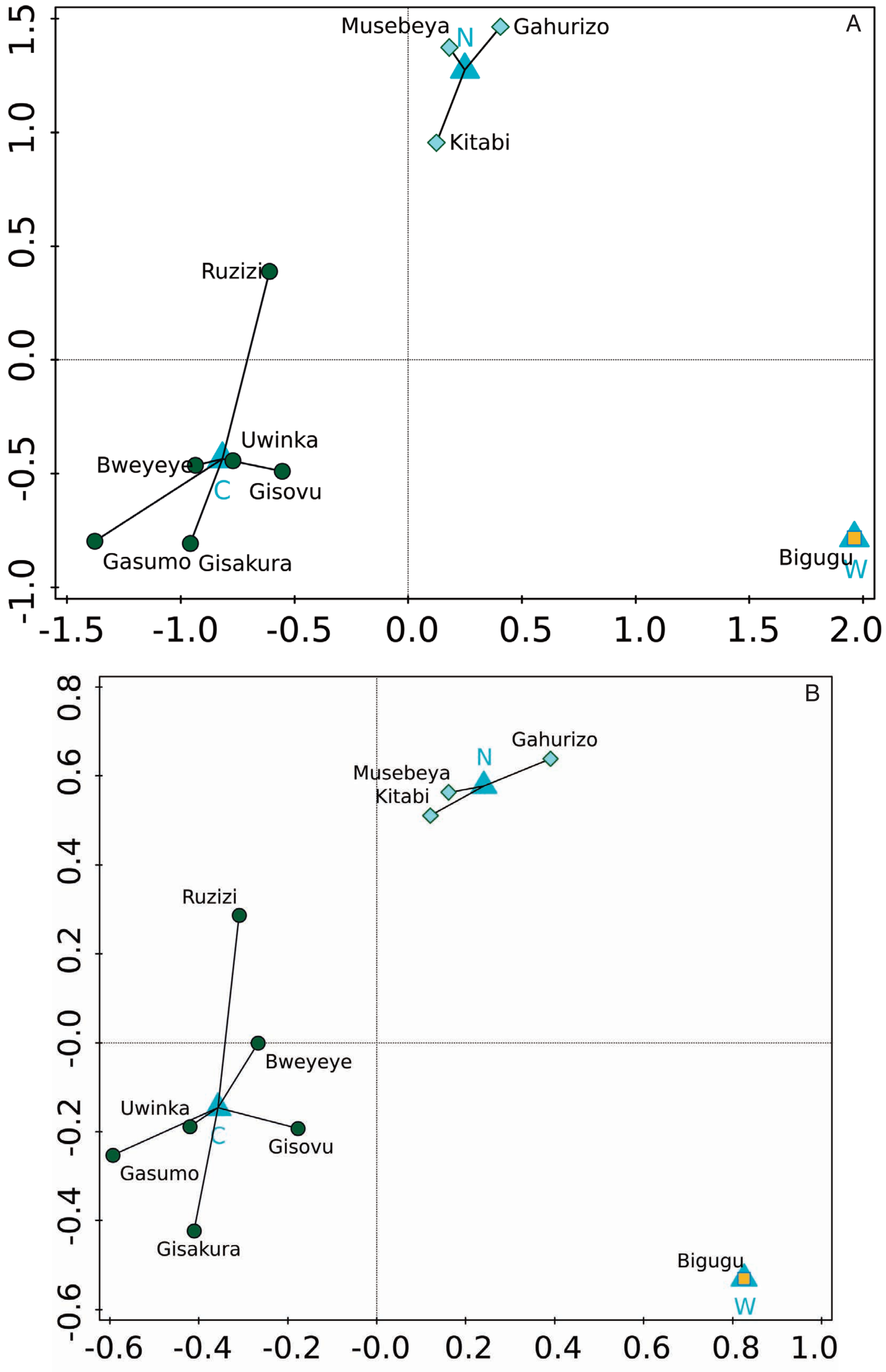


Figure 4.31: Star plots as before; here for Nyungwe only; pane A: result of CCA; pane B: result of tb-RDA

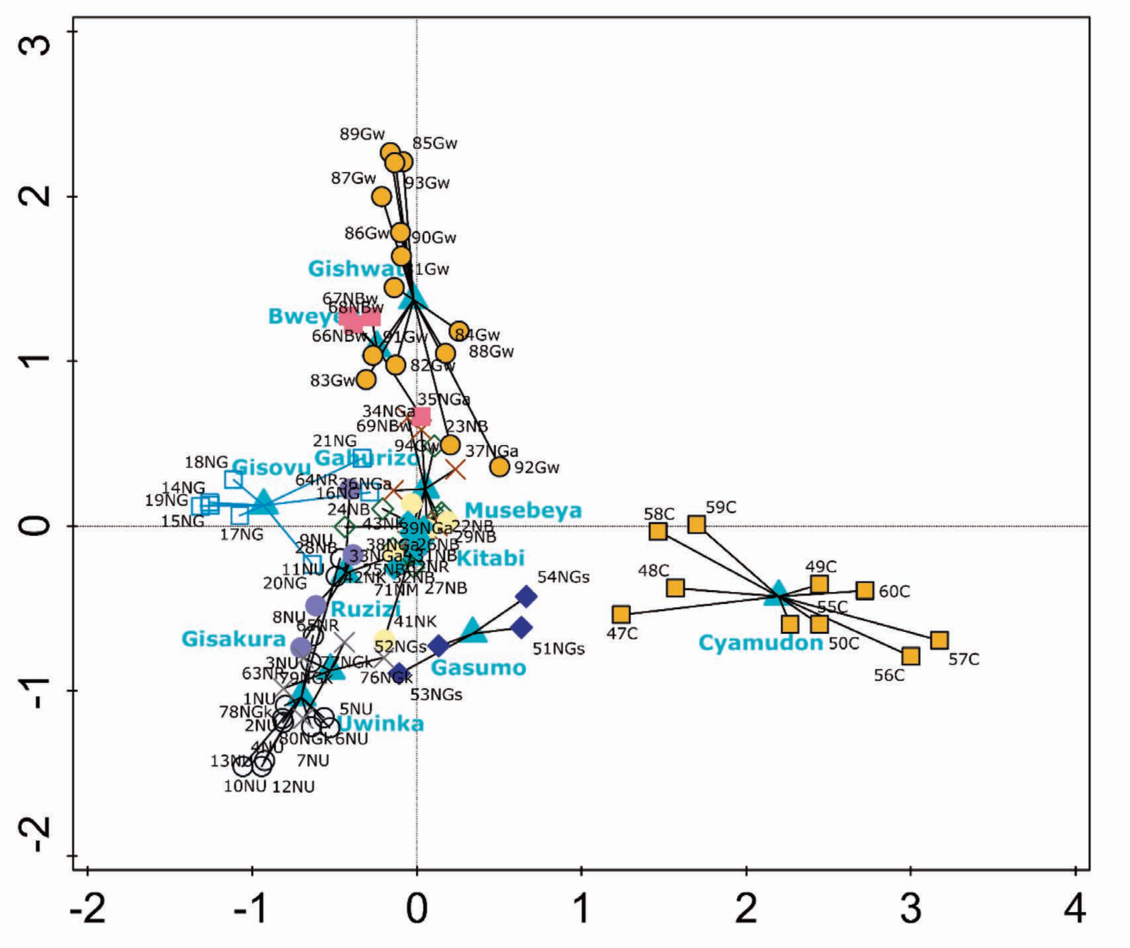


Figure 4.32: Star plot of the sample sites in relation to the respective nearest rangerstation as a result of CCA. The impact of the position towards the watershed was removed prior. Hill scaling was used to determine the axes.

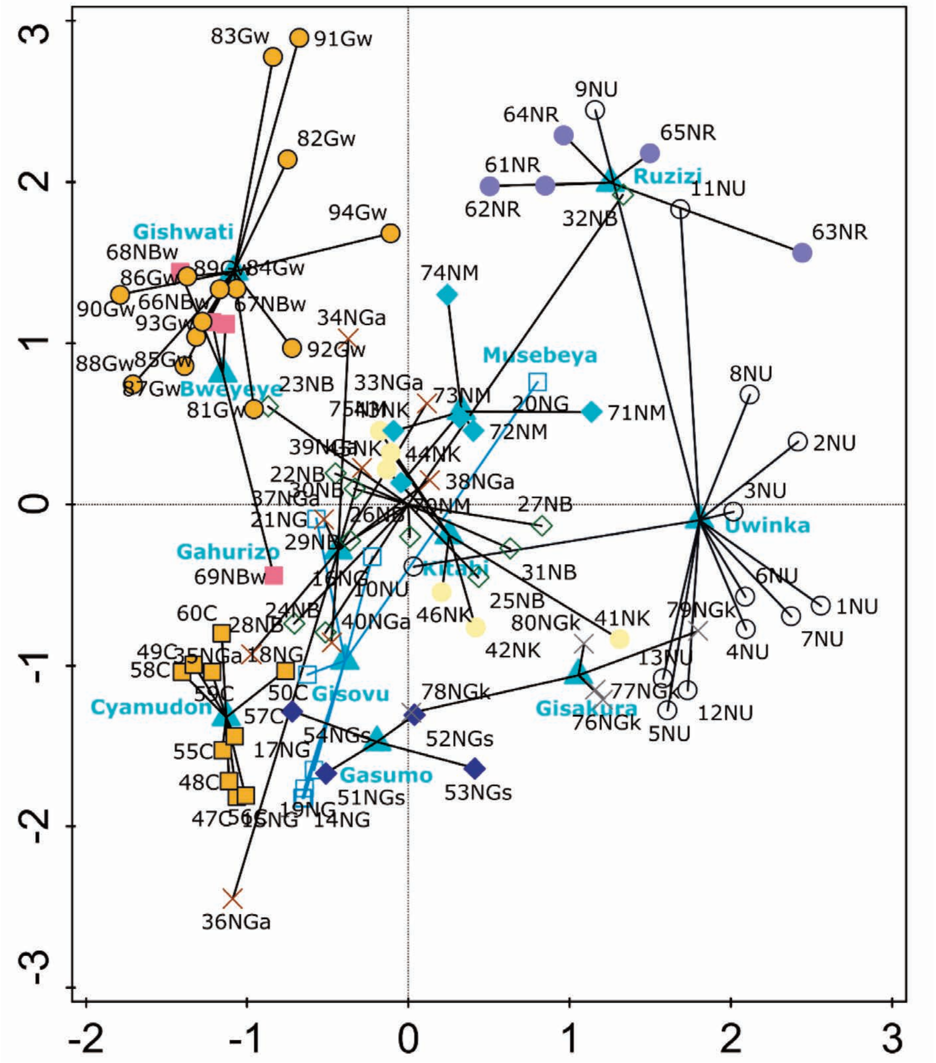


Figure 4.33: Star plot of the sample sites in relation to the respective nearest rangerstation as a result of tb-RDA. The impact of the position towards the watershed was removed prior. Hill scaling was used to determine the axes.

Employing the ranger stations as explanatory variables alone after removing the effect of the watershed-level, results in a variation explained of 15.30% (6.01%$_{\text{adj}}$) for the unimodal approach. Stemming from the linear concept, 23.03% (14.58%$_{\text{adj}}$) of the variation could be explained. Just as in the previous analyses, the similarities among the individual samples are sufficiently well represented despite the Euclidean distance used and the discussions under the previous points (3.2, 3.3) can be comprehended. From here we can turn to the impact of the environmental factors.

4.2.3 Canonical Correspondence Analysis

Since it was established in the preceding section that some of the variables are correlated, this information will thus be used to directly divide the environmental variables into subsections. Before this is carried out, a global validity test of the relation between the response variables and the explanatory variables was completed. The tests for soil parameters and the other impact variables have been carried out separately not just to reduce the number of explanatory variables but to individually inspect the impacts (Tab. 4.5 a, b). Both tests resulted in the rejection of the null hypothesis of no correlation between the respective explanatory variables and the responses. In a test conducted only on the first axis, albeit just, the null hypothesis of a single factor explaining the responses was also rejected (Tab. 4.5).

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.77	0.69	0.63	0.60	0.54
Explained variation (cumulative)	3.54	6.72	9.63	12.40	14.91
Pseudo-canonical correlation	0.98	0.96	0.95	0.94	0.94
Explained fitted variation (cumulative)	7.76	14.72	21.07	27.15	32.65

Table 4.5 a: CCA results. Test of H_0 using the environmental variables not pertaining to soil conditions. Permutation test results: pseudo-F <0.1, P = 0.038 for the first axis; pseudo-F = 1.3, P = 0.001 for all axes.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.81	0.78	0.74	0.68	0.65
Explained variation (cumulative)	3.71	7.33	10.75	13.86	16.86
Pseudo-canonical correlation	0.98	1.00	0.98	0.97	0.95
Explained fitted variation (cumulative)	6.26	12.35	18.10	23.35	28.39

Table 4.5 b: CCA results. Test of H_0 using the soil parametres. Permutation test results: pseudo-F <0.1, P = 0.001 for the first axis; pseudo-F = 1.5, P = 0.001 for all axes.

Two things emerge at this point. The soil-related explanatory variables extract more of the variation in the response data than the environmental variables not pertaining to soil properties (Table 4.5 a, b). In addition, both ordination graphs exhibit quite strong arch effects (not shown). Before the debatable[1] measure of detrending is resorted to, the advice of ŠMILAUER & LEPŠ (2014) will be followed. The authors stated that such an effect might likely disappear if correlated variables are removed from the analysis, and only variables with an important relation to the responses are kept (IBID.). Hence, the quadratic dependence of the second axis on the first one, established by said redundancy in the data, will be targeted for removal by applying an interactive stepwise forward selection. Evidence of such multicollinearity is given by the variance inflation factors listed in the respective log pages given by Canoco. A brief look reveals several factors beyond 20, declaring them as large, and several set to -0.0000, revealing a complete multicollinearity with the other factors (see Annex 6). This outcome holds true for both groups of explanatory variables, though to a much greater extent for the soil variables. Thus, the relatively high amounts of variation previously explained are set into perspective.

A third matter occurs at this point, albeit it is not a new one. Specific samples seem to have some properties that result in an ordination that places them quite far from the bulk of the samples. Among them are samples 10_{NU}, 57_C and 60_C. Again, if the samples are to be removed, will be sought out at a later point.

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[1] Depending on the detrending procedure used, the scores along axis two can be different and different ordinations can be obtained. Ecological interpretation especially when complex gradients are present should be avoided due to widely varying results (see discussion in: LEGENDRE & LEGENDRE, 2012).

4.2.3.1 Partial Ordination

In an endeavour to elucidate and eliminate the collinearities, the simple and conditional effects of the explanatory variables have been summarised by an analysis run in CANOCO. It has to be mentioned at this point that Canoco treats the states of the factor variables as variables of their own in terms of the centroid principle (ter Braak & Šmilauer, 2012). This process also means that the rarest factor state is also the most different and thus is projected in a corresponding distance from the other factor states. Despite samples 60_C and 57_C being close to the edge of the graph, as found by the unconstrained analysis as well, both are still the only samples that are close to an earth road through the forest and a mix of tree and tea plantations at the edge. This singularity gives rise to the relatively large contribution of that forest matrix state to the explanation of the gradient in the response variables. (Fig. 4.3). Form the figure, it becomes clear that the ordination is strongly biased, and not much of the actual variation has been displayed. Canoco 5 offers the option to both display the simple effects of the explanatory variables by describing the variation in the responses and also to display the conditional effects.

From Table 4.6 a, b, it emerges that elevation and temperature have the same share in explaining the variation in species composition. With the inclusion of elevation into the analysis, the contribution of temperature would drop to about 1%, and a p = 0.307 would give some reason to challenge the statistical significance of its impact. Further examples of related explanatory variables can be taken from the table.

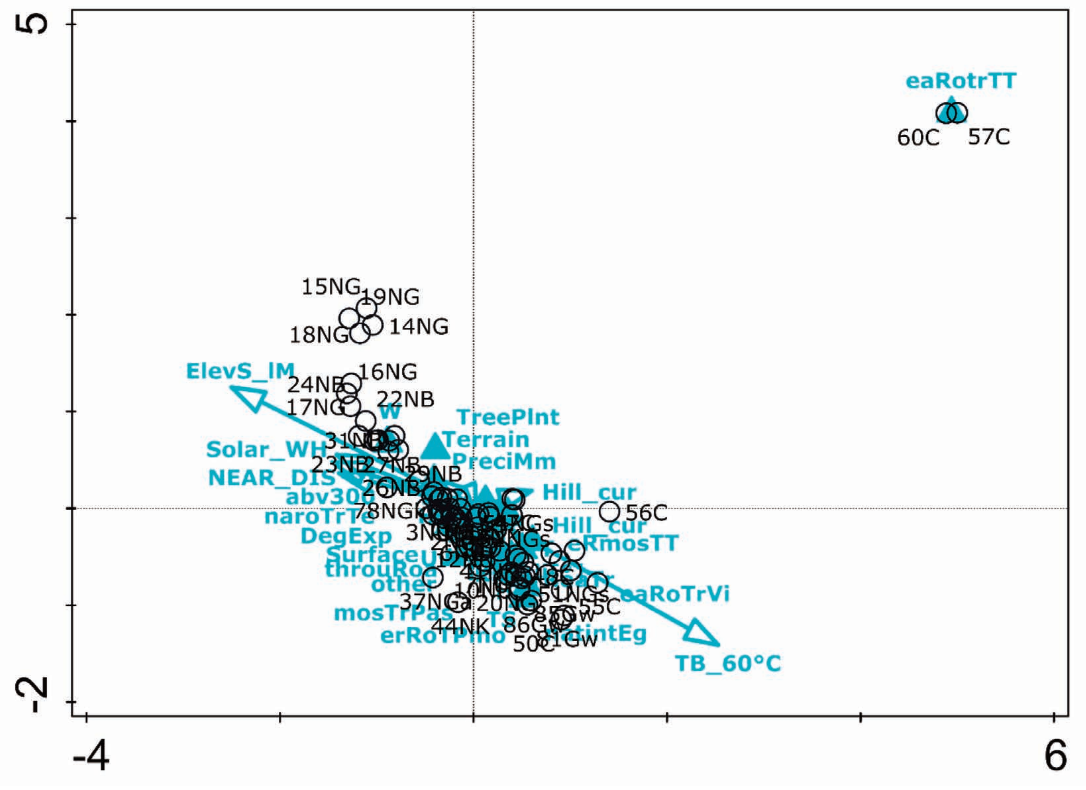

Figure 4.34: Scatterplot of the samples as projected on axes one and two. Illustrative example of an indiscriminate CCA approach. Hill scaling was used to determine the axes.

Name	Explains %	pseudo-F	P	P(adj)
Matrix.eaRotrTT	3.3	3.1	0.001	0.0036
Elev_a_ s_l m	3	2.8	0.001	0.0036
T B_60 °C	3	2.8	0.001	0.0036
Congo_Nile.W	2.4	2.2	0.001	0.0036
Congo_Nile.C	2.3	2.2	0.001	0.0036
NEAR_DIST	2.1	2	0.001	0.0036
Precip_a mm	2.1	2	0.001	0.0036
Matrix.Uwinka	1.9	1.8	0.015	0.04154
Matrix.abv300	1.8	1.7	0.001	0.0036
Matrix.TreePlnt	1.8	1.7	0.003	0.009
Terrain	1.7	1.6	0.001	0.0036
Congo_Nile.N	1.7	1.6	0.001	0.0036
Solar_WHm2	1.7	1.6	0.002	0.00655
Matrix.eRmosTT	1.6	1.5	0.059	0.13275
Matrix.trghRoEa	1.6	1.5	0.098	0.20753
Matrix.erRoTPmo	1.4	1.3	0.199	0.3582
Position_Relief.HO	1.4	1.3	0.033	0.08486
Inclination [°]	1.3	1.2	0.054	0.1296
Matrix.natintEg	1.3	1.2	0.282	0.42267
Matrix.mosTT	1.3	1.2	0.233	0.39943
Hill_curv_para	1.3	1.2	0.174	0.32968
Hill_curv-transv	1.3	1.2	0.129	0.258
Matrix.throuRoa	1.2	1.1	0.266	0.41635
Matrix.naroTrTe	1.2	1.1	0.264	0.41635
Matrix.other	1.2	1.1	0.313	0.42267
Position_Relief.HM	1.1	1	0.317	0.42267
Deg Exp	1.1	1	0.317	0.42267
Position_Relief.HU	1.1	1	0.42	0.51794
Surface	1.1	1	0.446	0.51794
Matrix.eaRoTrVi	1.1	1	0.427	0.51794
Position_Relief.KH	1.1	1	0.488	0.549
Position_Relief.KM	0.9	0.9	0.446	0.51794
Position_Relief.TS	0.9	0.8	0.505	0.55091
Matrix.earRoaTree	0.8	0.8	0.8	0.8
Position_Relief.MH	0.7	0.7	0.645	0.68294
Position_Relief.KS	0.6	0.6	0.77	0.792
Matrix.Tea	0.6	0.5	0.887	0.887
Matrix.mosTrPas	0.5	0.5	0.931	0.931
Position_Relief.KR	0.4	0.4	0.873	0.873

Table 4.6 a: P(adj) obtained by the correction for false discovery rate; a/ The simple effects of the environmental parameters ordered by percentage explained. b/ (see next page) The conditional effects of the environmental parameters. The percentage explained and P-values were obtained per Monte-Carlo permutation, after the inclusion of the predictors placed above in the list. From the difference in the orders of the variables in the respective table, correlations between the variables can be inferred.

Name	Explains %	pseudo-F	P	P(adj)
Matrix.eaRotrTT	3.3	3.1	0.002	0.0144
Elev_a_ s_l m	2.89	2.8	0.001	0.009
Precip_a mm	2.22	2.2	0.001	0.009
Matrix.TreePlnt	1.83	1.8	0.001	0.009
Matrix.Uwinka	1.81	1.8	0.008	0.04114
Matrix.trghRoEa	1.61	1.6	0.057	0.14657
Congo_Nile.N	1.68	1.7	0.001	0.009
Matrix.eRmosTT	1.48	1.5	0.053	0.14657
Congo_Nile.W	1.44	1.5	0.005	0.03
Congo_Nile.C	1.44	1.5	unknown	unknown
Matrix.throuRoa	1.31	1.4	0.05	0.14657
NEAR_DIST	1.37	1.4	0.051	0.14657
Position_Relief.KM	1.58	1.7	0.069	0.1656
Inclination [°]	1.22	1.3	0.041	0.14657
Hill_curv-transv	1.22	1.3	0.054	0.14657
Matrix.erRoTPmo	1.19	1.3	0.179	0.37906
Matrix.mosTT	1.15	1.2	0.2	0.3798
Deg Exp	1.13	1.2	0.104	0.234
Matrix.naroTrTe	1.09	1.2	0.206	0.3798
Hill_curv_para	1.06	1.1	0.211	0.3798
Matrix.natintEg	1.04	1.1	0.296	0.4536
Matrix.abv300	1.2	1.3	0.052	0.14657
Matrix.other	1.01	1.1	0.305	0.4536
Position_Relief.TS	1.01	1.1	0.313	0.4536
T B_60 °C	1	1.1	0.307	0.4536
Matrix.earRoaTree	0.96	1	0.366	0.50677
Position_Relief.HM	0.95	1	0.439	0.58533
Terrain	0.99	1.1	0.315	0.4536
Position_Relief.HO	0.9	1	0.557	0.69329
Position_Relief.HU	0.84	0.9	0.683	0.74509
Position_Relief.MH	0.84	0.9	0.597	0.69329
Position_Relief.KS	0.85	0.9	0.581	0.69329
Matrix.eaRoTrVi	0.86	0.9	0.579	0.69329
Solar_WHm2	0.83	0.9	0.722	0.76447
Surface	0.79	0.8	0.661	0.74362
Matrix.Tea	0.66	0.7	0.898	0.92366
Matrix.mosTrPas	0.66	0.7	unknown	unknown
Position_Relief.KR	0.35	0.4	0.976	0.976

Table 4.6 b: The conditional effects of the environmental parameters. For a description see the captions under 4.6 a.

In order to select a subset of the environmental variables ascertained in the field, the effects of the variables were evaluated, after removing conditional effects, in terms of their contribution and statistical significance. The interactive forward selection procedure implemented into Canoco made it possible to reduce the number of explanatory variables to six[2], making elevation a.s.l. the most influential variable. When perusing the Log page, it becomes apparent that most of the inflated variance, i.e., multicollinearity has been eliminated. The skewness brought about by samples 57_C and 60_C is still present though. Using the option of setting weights for the samples, both have been weighted down by a factor of 0.15. This setting renders the removal of the examples superfluous and prevents the unnecessary loss of information.

As a reminder, with all 14 environmental variables included, the explanatory variables accounted for 45.68% ($11.37\%_{adj}$) of the variation in the response variables. This result also includes a substantial amount of multicollinearity as evidenced by the inflation factors given on the Log page (Annex 6). Interactive forward selection with down weighing of two samples lowered the amount of explained variation to 21.59 % ($9.97\%_{adj}$). When considering the adjusted coefficients, the decrease seems reasonable since almost all of the multicollinearity has been removed.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.70	0.56	0.53	0.50	0.40
Explained variation (cumulative)	3.29	5.90	8.36	10.68	12.57
Pseudo-canonical correlation	0.96	0.93	0.87	0.98	0.87
Explained fitted variation (cumulative)	15.24	27.33	38.71	49.47	58.21

Table 4.7 a: CCA results after interactive forward selection of the environmental variables. Eigenvalues quantify the importance of the respective calculated axes. The values vary between 0 and 1. Explained variation (cumulative) is the cumulative percentage of variance in the response data accounted for by the axes. Pseudo-canonical correlation is the correlation between the case scores of the axis stemming from the responses and the corresponding case scores stemming from the explanatory data. Canoco does not maximise this correlation, hence, the Pseudo-. Canoco maximises the explained variation. Explained fitted variation (cumulative) is the cumulative percentage variance in the fitted responses explained by the axes.

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
Elev_a_ s_l m	3	6.6	2.8	0.001	0.004
Precip_a mm	2.3	5	2.2	0.001	0.006
NEAR_DIST	1.6	3.6	1.6	0.001	0.006
Congo_Nile.N	1.7	3.8	1.7	0.001	0.00514
Congo_Nile.C	1.6	3.5	1.6	0.001	0.0072
Congo_Nile.W	1.6	3.5	1.6	0.002	0.012
Matrix.TreePlnt	1.6	3.6	1.6	0.002	0.01029
Matrix.Uwinka	1.7	3.7	1.7	0.01	0.045
Inclination [°]	1.4	3	1.4	0.009	0.04
Matrix.eaRotrTT	2.3	5.1	2.3	0.012	0.0432
Matrix.trghRoEa	1.6	3.5	1.6	0.025	0.075
Matrix.eRmosTT	1.5	3.3	1.5	0.024	0.072
Matrix.throuRoa	1.4	3.1	1.4	0.034	0.09415

Table 4.7 b: Results of CCA using interactive forward selction. Total variation = 21.39112, Explanatory variables account for 21.89 % (9.97 %adj); Table b includes the selected variables and variable states of the factor variables. P(adj) established on the basis of false discovery rate. See Annex 7 A for VIFs.

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[2] Remember: Canoco treats the states of factor variables as a single variable. Hence the eleven items chosen.

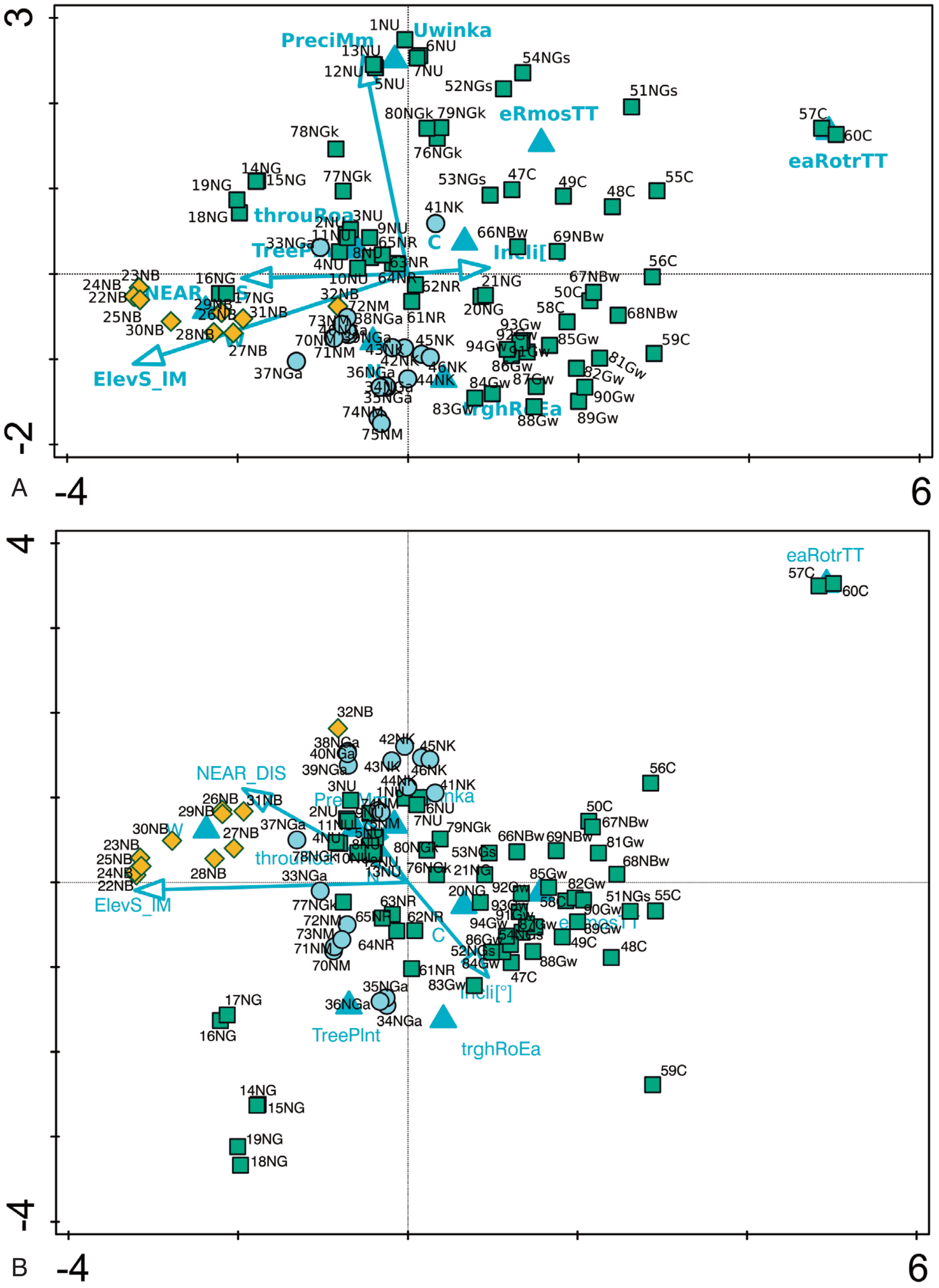

Figure 4.35 A, B: Biplot of the samples and explanatory variables as projected on axes one and two (a) and one and three (b). Illustrative example of an indiscriminate CCA approach. The impact of samples 57C and 60$_C$ is readily conceiveable. The samples from the Congo side of the watershed are displayed as green squares. Light blue circles symbolise the samples from the Nil side, and the position on the watreshed is indicated by orange rhombuses. Hill scaling was used to determine the axes.

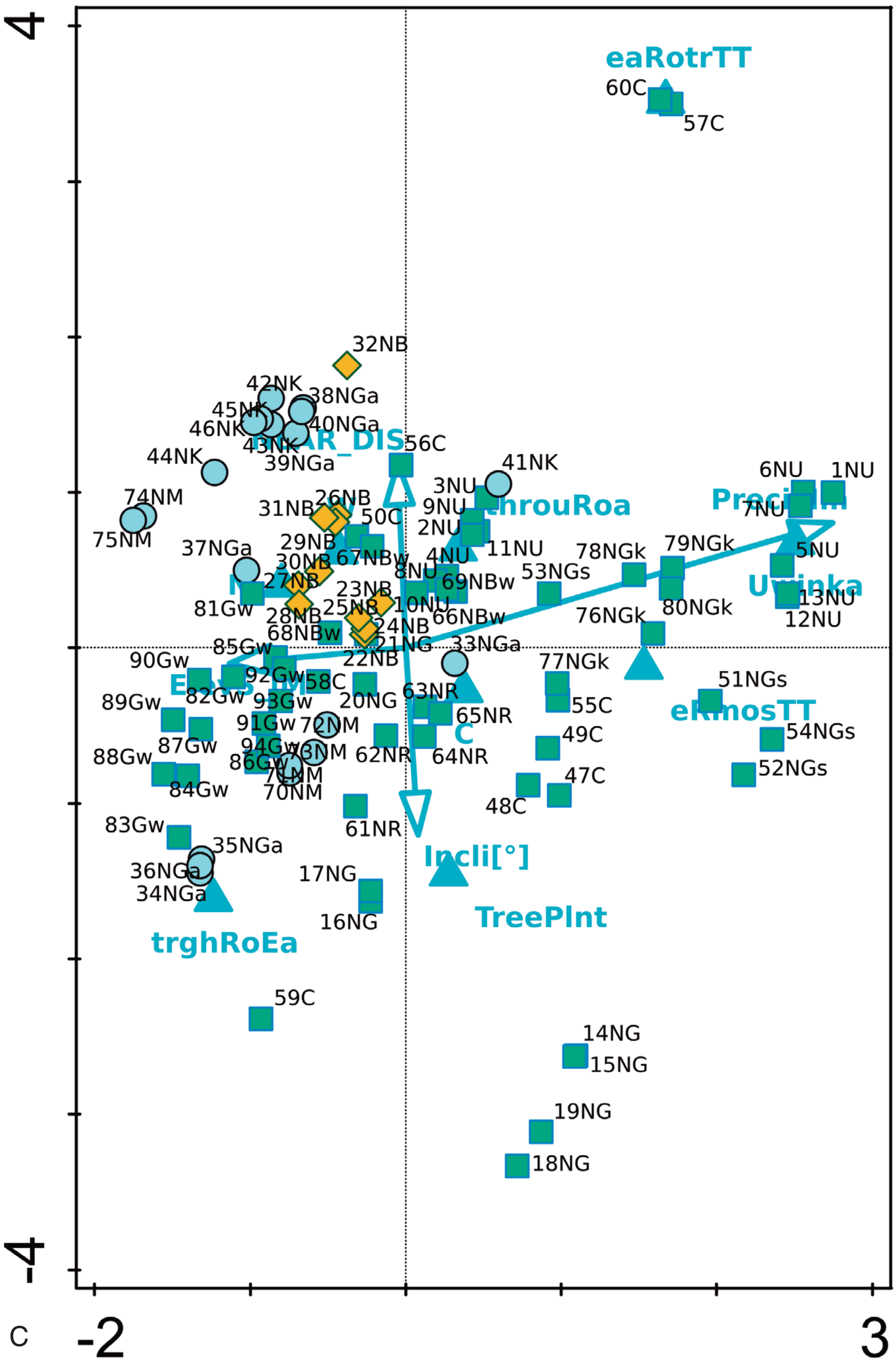

Figure 4.35 C: Biplot of the samples and independent variables as projected on axes two and three. Hill scaling was used to determine the axes.

The last three inclusions of the matrix states however, fall outside of the 0.05 alpha-level of significance for the corrected p-values. In an attempt to stay on the safe side, the exclusion of the last three matrix states led to an increased bias induced again by both samples from Cyamudongo forest. Hence, both samples had to be excluded. With this done, explanatory power dropped to 15.67 % (7.54 %adj).

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.69	0.53	0.47	0.40	0.34
Explained variation (cumulative)	3.39	6.00	8.30	10.26	11.92
Pseudo-canonical correlation	0.95	0.92	0.84	0.86	0.80
Explained fitted variation (cumulative)	21.62	38.29	52.96	65.47	76.11

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
Elev_a_ s_l m	3.1	6.9	2.9	0.001	0.0035
Precip_a mm	2.4	5.3	2.2	0.001	0.00438
NEAR_DIST	1.7	3.8	1.6	0.001	0.005
Matrix.Uwinka	1.9	4.3	1.8	0.002	0.00875
Congo_Nile.N	1.8	3.9	1.7	0.001	0.007
Matrix.TreePlnt	1.7	3.8	1.6	0.002	0.00875
Congo_Nile.W	1.5	3.4	1.5	0.003	0.015
Congo_Nile.C	1.5	3.4	1.5	0.006	0.02625
Matrix.throuRoa	1.6	3.6	1.6	0.01	0.035

Table 4.8 a, b: Results of CCA using interactive forward selction. Total variation = 20.46046, Explanatory variables account for 15.67 % (7.54 %$_{\text{adj}}$); Table b includes the selected variables and variable states of the factor variables. P(adj) established on the basis of false discovery rate. See Annex 8 A for VIFs.

Though the overall drop in the explanatory value from 11.37%$_{\text{adj}}$ to 9.97%$_{\text{adj}}$ and finally to 7.54%$_{\text{adj}}$ seems not too steep, curiosity remained as to the contribution of the environmental parameters left out. Consequently, the possibility of a partial constrained analysis was explored. After taking the mentioned environmental variables into account, the analysis, which should have accounted for the part of the variation in the reponses still present after removing the effect of the variables known to have an impact, proved to be statistically insignificant and was, thus, pointless.[3] It follows that the environmental variables left, including temperature, do not have a significant unique impact on species composition, i.e., turnover.

The second outcome of interactive forward selection leaves the results with a total variation of 21.39$_{\text{SD}}$ of which 21.59% (9.97%$_{\text{adj}}$) are accounted for by the explanatory variables included in the analysis. Of these, the variables elevation a.s.l., mean annual precipitation, the positioning in respect to the watershed and the distance to the forest margin are the most pertinent. Likewise, inclination contributes to the dissimilarities in species composition. It remains to be seen if the 1.4% variation explained by the variable are not a proxy and integrate the impact of other variables. Several states of the matrix variable have been incorporated as well. Most of them contain roads, be it earth roads or tarmac. Tree plantations seem to be of explanatory value as well. During the analysis, most of the collinearity between the environmental variables has been removed (Annex 7, 8). The factor state Congo side of the watershed seems to have some spurious relation to the forest matrix.

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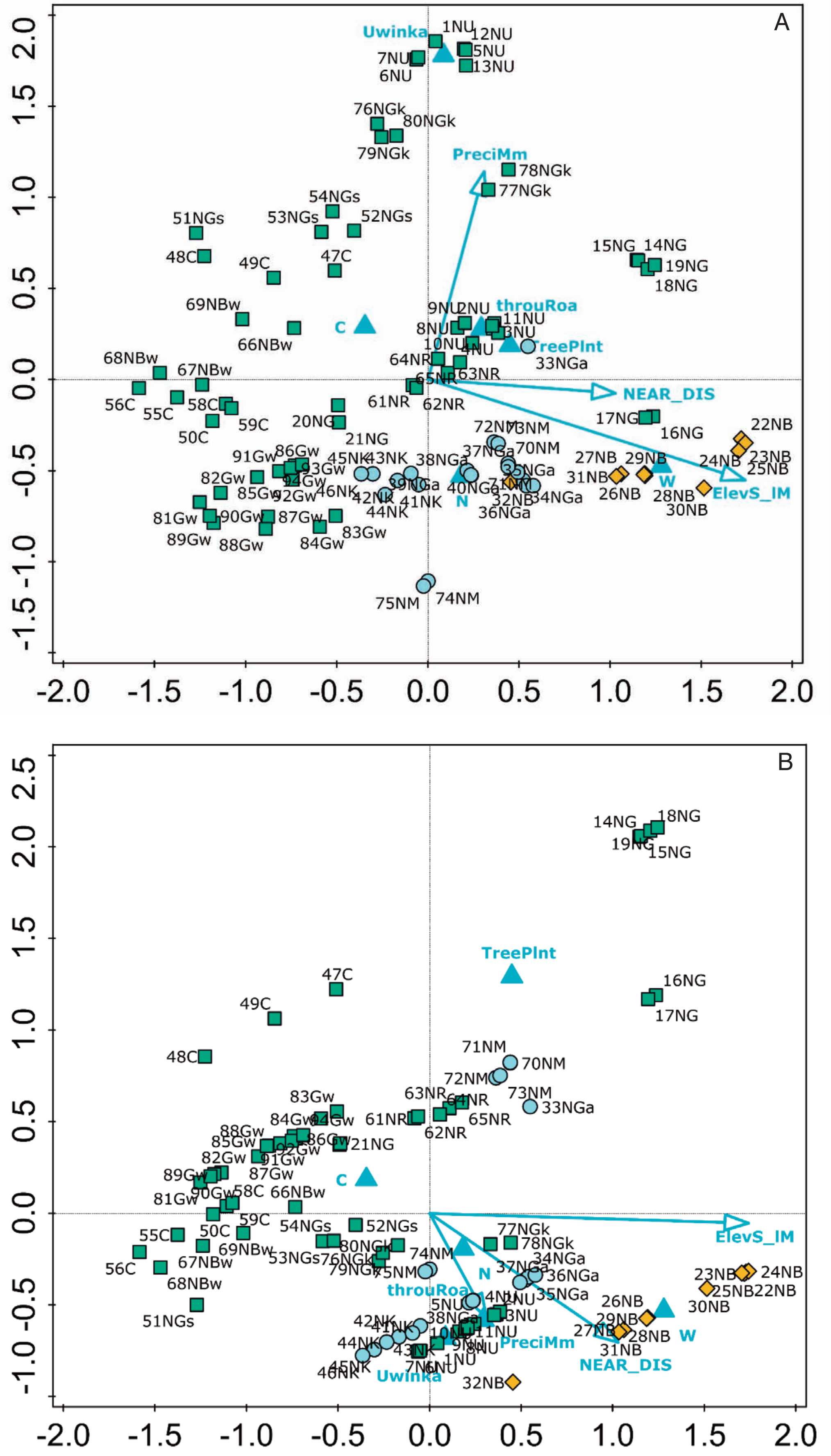
[3] Based on the permutation tests of the first axis with F = 0.1, P = 0.537 and all axes F = 1.0, P = 0.387, the null hypothesis could not be rejected.


A
Uwinka
PreciMm
throuRoa
TreePlnt
NEAR_DIS
ElevS_IM
C
N
W
1NU
12NU
5NU
13NU
7NU
6NU
76NGk
80NGk
79NGk
78NGk
77NGk
54NGs
51NGs
53NGs
52NGs
48C
49C
47C
15NG
14NG
19NG
18NG
69NBw
66NBw
9NU
2NU
11NU
8NU
3NU
10NU
4NU
33NGa
64NR
63NR
65NR
68NBw
67NBw
56C
55C
58C
59C
50C
20NG
61NR
62NR
17NG
16NG
22NB
21NG
72NM
73NM
70NM
91Gw
86Gw
45NK
43NK
38NGa
37NGa
93Gw
82Gw
94Gw
85Gw
92Gw
46NK
39NGa
42NK
41NK
40NGa
71NM
35NGa
34NGa
32NB
36NGa
27NB
29NB
31NB
26NB
28NB
30NB
24NB
23NB
25NB
81Gw
90Gw
87Gw
44NK
83Gw
89Gw
88Gw
84Gw
75NM
74NM
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
B
14NG
18NG
19NG
15NG
16NG
17NG
47C
49C
48C
71NM
70NM
72NM
73NM
33NGa
63NR
64NR
65NR
61NR
62NR
83Gw
84Gw
94Gw
88Gw
85Gw
86Gw
21NG
92Gw
91Gw
82Gw
89Gw
87Gw
81Gw
90Gw
58C
66NBw
55C
50C
59C
54NGs
52NGs
56C
69NBw
67NBw
68NBw
53NGs
76NGk
80NGk
79NGk
75NM
74NM
77NGk
78NGk
34NGa
37NGa
36NGa
35NGa
51NGs
4NU
2NU
3NU
5NU
38NGa
11NU
42NK
41NK
10NU
44NK
43NK
9NU
8NU
1NU
7NU
6NU
45NK
46NK
26NB
29NB
27NB
28NB
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22NB
30NB
-1.0
-0.5
2.5

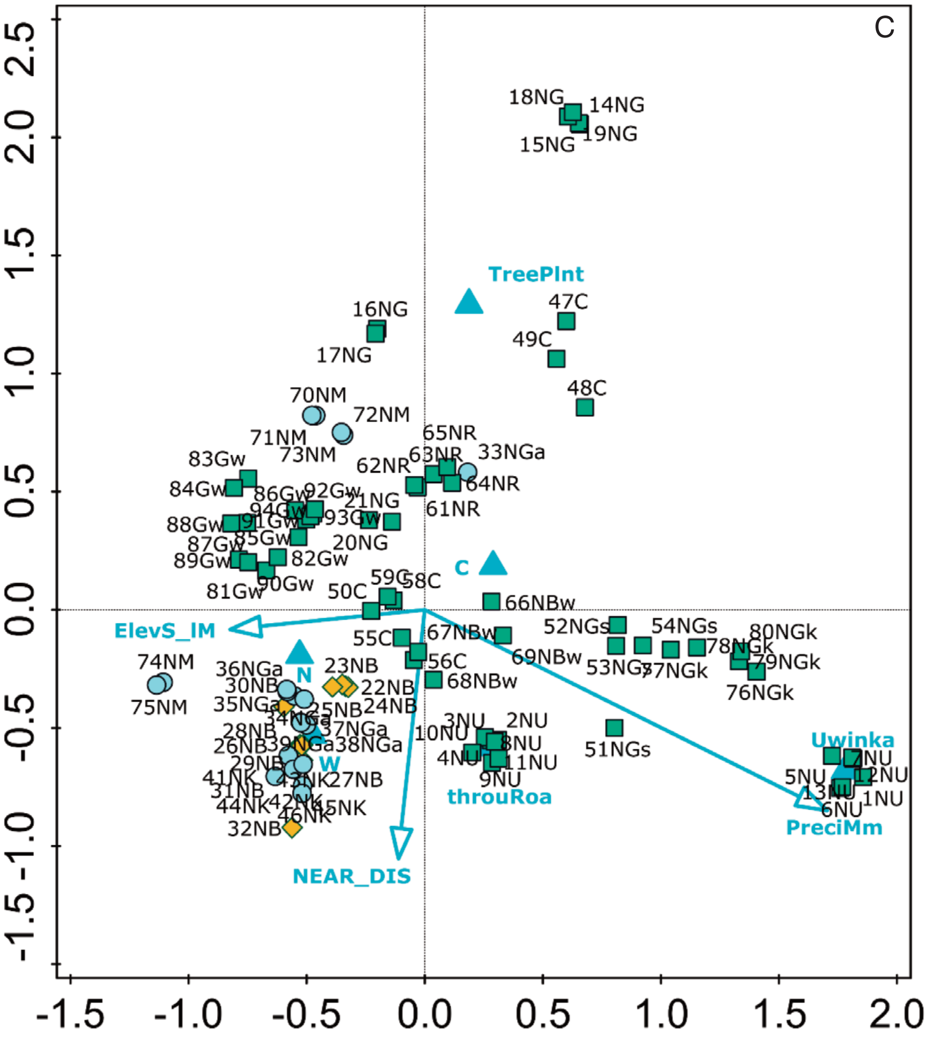

Figure 4.36 A-C: Biplot of the samples and explanatory variables as projected on axes one, two and three, respectively. The number of samples was reduced by two. The matrix states comprsing unpaved roads were omitted. The samples from the Congo side of the watershed are displayed as green squares. Light blue circles symbolise the samples from the Nil side, and the position on the watreshed is indicated by orange rhombuses. Biplot scaling was used to determine the axes.

Figures 4.36 A-C provide some more details as to the separation of the samples along axes one to three. Axes one and two show the usual separation along the elevational gradient, with the samples from Mts Bigugu and Muzimu on the one end, and the samples from Cyamudongo on the other. The gradient in precipitation is illustrated by axis two. However, the interrelations of the explanatory variables here foster an erroneous interpretation when it comes to the samples from Uwinka and Gisakura. Albeit Uwinka is on the high end of the precipitation scale, the sites at Gisakura and Gasumo receive higher rainfall. The separation of samples from one ranger station, except for sample 32_{NB}, as found with unconstrained analysis could not be found here, at least not to the same extent. The samples from Gishwati Forest are positioned quite close together. The Gahurizo and Ruzizi samples are, likewise, in close proximity. Only sample 41_{NK} from Kitabi seems to be more similar to some sites from the Congo side. Some close relations may also be existing between some samples from Cyamudongo and Gishwati Forest as well as Bweyeye. Axes one and three display the gradients in distance to the forest margin and inclination. Although the overall ordination reflects the general structure, in detail, faulty inferences can be drawn. The samples from Kitabi cover the whole gradient from almost flat to steep, yet they are positioned close together. This outcome, however, represents their altitudinal situation quite correctly. A plot of axes two and three again might lead to misinterpretation. The general positioning along the vectors of inclination and distance to the forest matrix gives a good overview, but the positioning of the samples does not reflect the true values. However, samples 14_{NG} and 15_{NG} are on steeper grounds than, e.g., sample 32_{NB}, inclination at the sites is still at the lower end of the scale. Sample 76_{NGk} is situated on much steeper terrain, for example.

In the pursuit of a more stable result, while incurring a loss of information in exchange for statistical purity, the total variation decreased to 20.46_{SD} due to the exclusion of two samples. The explanatory variables account for $7.54\%_{adj}$ of variation explained. Not only were the matrix states carrying little statistical significance left out, but also inclination dropped out of the analysis. The matrix states left, include the Uwinka visitor centre, the road running through Nyungwe forest and tree plantations forming the buffer zone. The rest of the impact variables remained the same. The explanatory values of which can be taken from table 4.8 b. With the exclusion of the mentioned variables, the interpretation of the biplots follows the same reasoning as above. In difference to the afore shown biplots, the graphs from Fig. 4.36 a to c are displayed with biplot scaling to provide a comprehensive overview.

In the next step, the same procedure was performed for the soil variables. Here, analysis proved quite intricate or at least cumbersome. As every ordination comprises some truth, the laborious decision on a suitable combination of soil parameters was based on minimising conditional effects and maximising the significance of the respective variables.

When first fitting the model to the data, quite a lot of multicollinearity between the soil variables was detected, rendering the explained variation of 59.37% ($19.60\%_{adj}$) problematic and unstable (see Annex 6 B for the conditional and simple effects of the soil parameters). In addition, some of the samples exhibit extreme values in some of the soil variables, thereby introducing strong bias into the results and complicating the interpretation of the diagrams. Yet, these variables and samples may not be omitted since their explanatory value is of the essence. The option to weight individual samples provided by Canoco has been employed for samples 10_{NU}, 57_{C} and 60_{C}.

Since sample 10_{NU} has a preeminent impact on ordination and is the only one situated on silty loam, which gives the corresponding bias, it has been given a weight of 0.22. This provision minimises the impact, and it results in a loss of statistical significance of the factor state during interactive stepwise forward selection such that it was excluded from the further selection process. Half of the samples from Cyamudongo Forest are situated on soils containing little aluminium combined with elevated magnesium and calcium levels. This results in some of the highest ratios of [Mg]:[Al] and [Ca]:[Al]. In turn, both ratios impact ordination to a massive extent. In particular, samples 60_{C} and 57_{C} exert steep leverage. While the impact of sample 57_{C} needed only to be halved, a factor of 0.015 had to be applied to sample 60_{C} to gain control of the impact. The procedure resulted in the loss of statistical significance of both ratios. Any increase in the weights set resulted in skewness of the diagram. The same is valid for the inclusion of the ratios of [Mg], [Ca] and [Al] mentioned above. On the other hand, further decrease in the weight given to sample 60_{C} was to no avail. As has been already the case with indirect ordination, [Mg] has been included in the analysis. New to the analysis is the [P]. The total variation remaining after setting the weights for the samples mentioned is 20.96_{SD}, of which 22.36% ($10.86\%_{adj}$) are extracted by the soil variables. Most prominent are the [C]:[N] ratio, the geology and pH. The steep decrease in explained variation goes along with almost no multicollinearity left in the explanatory variables, as evidenced by the variance inflation factors (VIF) (Annex 7 B).

The complete omission of [Al], [Mg] and [Ca] in comparison with the unconstrained ordination gave rise to an explorative attempt within which sample 60_C has been treated as a supplementary variable, i.e., not included in the analysis but enforced in the graph. Since the weighting process of the samples is determined merely by the user, some experimentation ensued. As a result, the weight given to sample 10_{NU} had to be lowered to 0.15, and the one given to sample 57_C had to be lowered to 0.45. The exclusion and further weight reduction of the respective samples shortened the variation to 20.76_{SD}, of which now 20.10% (10.35%$_{adj}$) are accounted for by explanatory variables. From Table 4.9 b it can be seen that the [Ca]:[Al] ratio could be included as well as the [Mg]. The Log page (Annex 8) provided shows that no unnecessary variance inflation has been added due to the inclusion of neither the ratio or the additional variable.[4]

The variables left out were tested for effects as covariates by a partial analysis. The results were the same as before with the environmental parameters not being significant either on the trace (P = 0.342) or on the first axis (P= 0.887).

The three graphs produced (Fig. 4.37 A-C) exhibit the same ordination as has been found by indirect ordination. The samples from Mts Bigugu and Muzimu are projected towards the higher end of the [C]:[N] ratio while, at the same time, show a negative correlation to pH. Cyamudongo Forest is separated by high ratios of [Ca]:[Al] and [Mg]:[Al], while the samples from Gishwati Forest likewise show elevated pH values.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.72	0.66	0.55	0.46	0.42
Explained variation (cumulative)	3.46	6.66	9.31	11.54	13.55
Pseudo-canonical correlation	0.95	0.94	0.88	0.90	0.88
Explained fitted variation (cumulative)	17.24	33.16	46.34	57.43	67.42

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
[C]:[N]	3.1	5.3	2.9	0.001	0.00327
pH	2.2	3.8	2.1	0.001	0.00377
Cat_Geol.SlateMylo	2.6	4.5	2.6	0.001	0.0049
Cat_Geol.Quarzitic	2.2	3.7	2.1	0.001	0.00544
[Ca]:[Al]	2.1	3.7	2.1	0.001	0.007
Cat_Geol.GraniteSedi	1.6	2.7	1.6	0.001	0.007
Soiltype_FAO.HAHF	1.7	2.9	1.7	0.004	0.0196
Soiltype_FAO.HAHFC	1.4	2.4	1.4	0.003	0.0147
[Mg]	1.7	2.8	1.7	0.005	0.02722
Limitation.stone	1.4	2.4	1.4	0.007	0.0343

Table 4.9 a, b: Results of CCA using interactive forward selction. Total variation = 20.76006, Explanatory variables account for 20.10 % (10.35 %$_{adj}$); Table b includes the selected variables and variable states of the factor variables. P(adj) was established on the basis of false discovery rate. For VIFs see Annex 8 B)

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[4] Further experimentation increased the variation explained to 33.09% (adjusted: 16.82%). Though this increase might be desirable, the additional variables included brought about increased multicollinearity as well. Hence, the raise in explanatory power might be spurious.

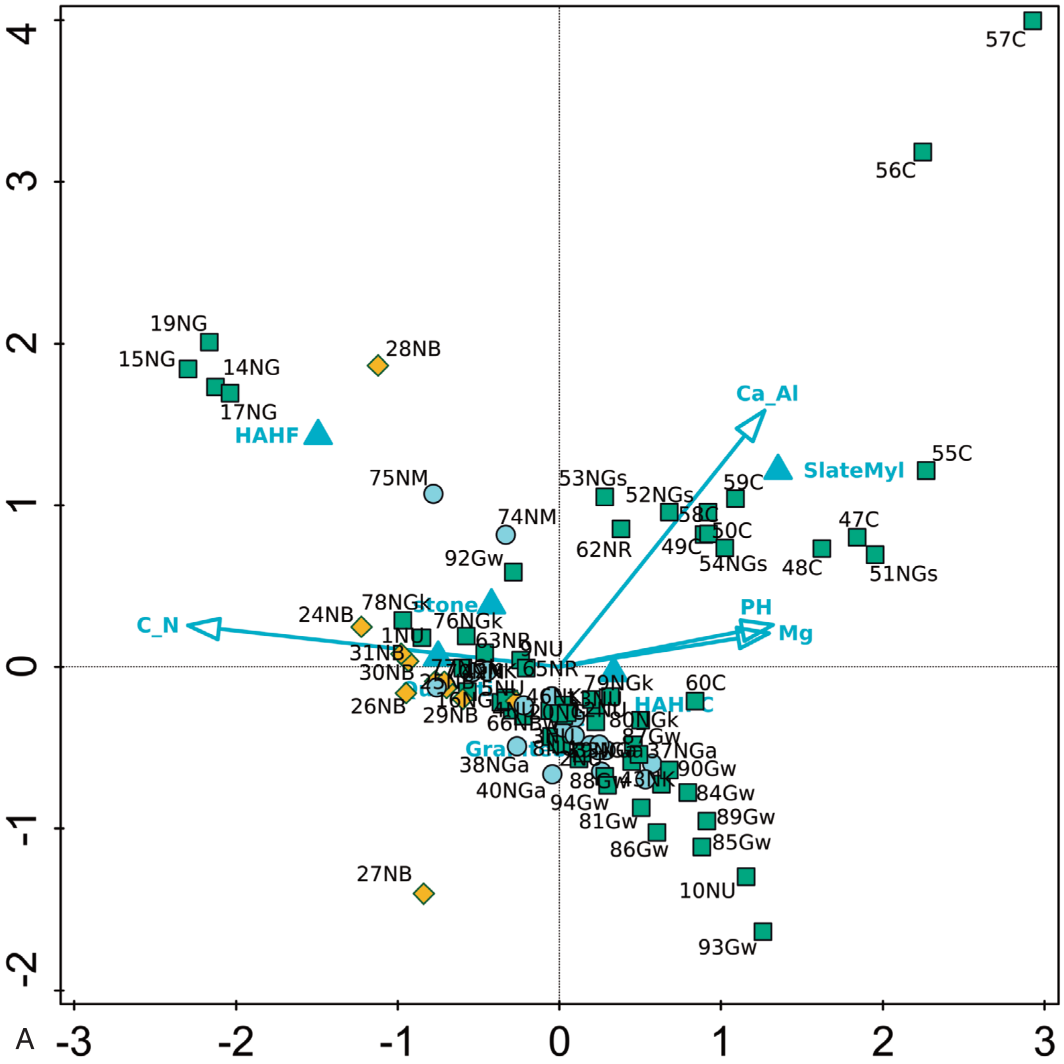

Figure 4.37 A: Biplot of the samples and independent variables as projected on axes one and two. Both axes together depict 6.66% of the variation explained by the soil variables. Biplot scaling was used to determine the axes. See Annex 8 B for VIFs.

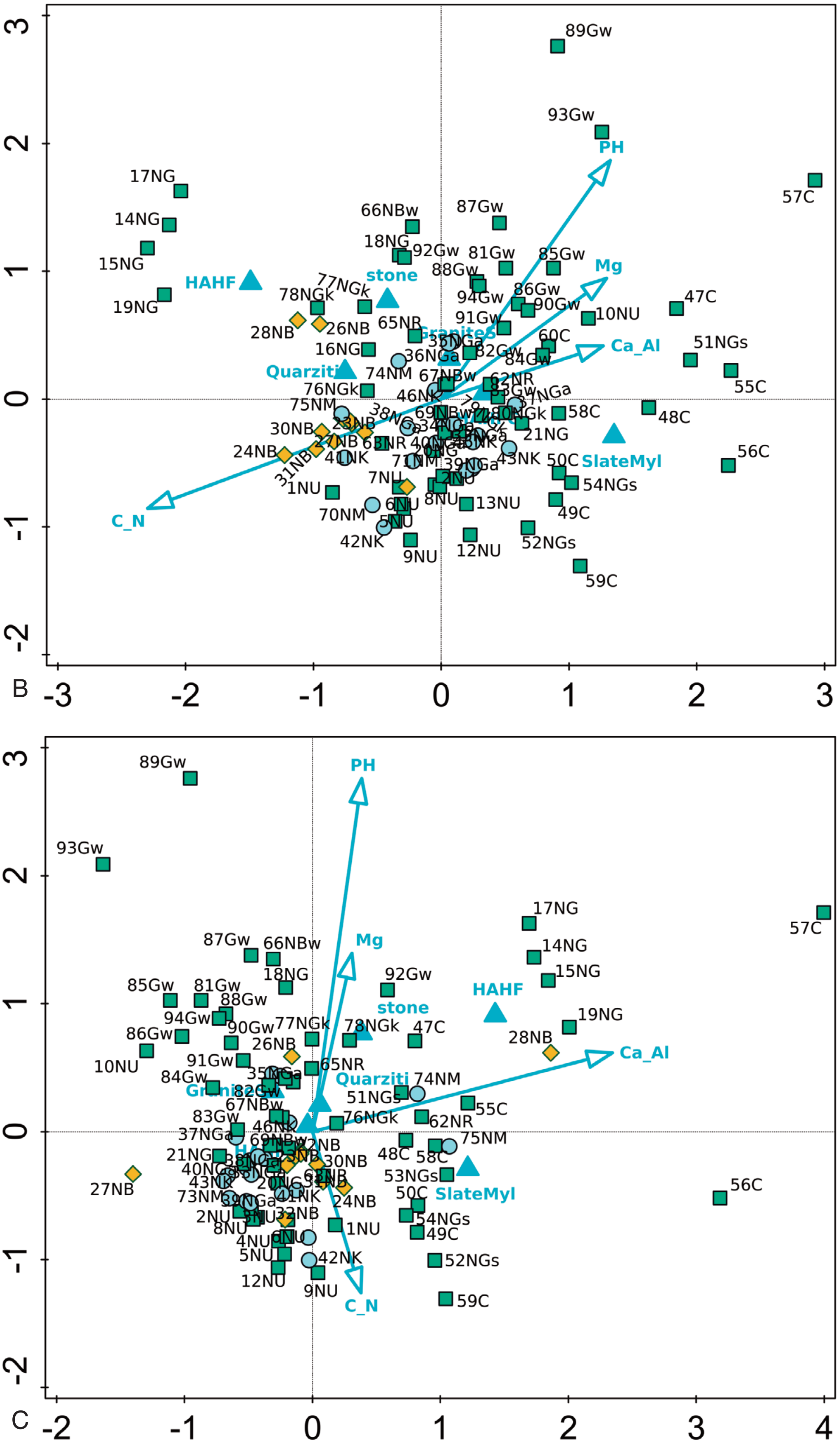

Figure 4.37 B, C: A biplot of axes one and three is given in pane B. Axes two and three are depicted in pane C.

Since the environmental variables are deemed to have an impact on soil parameters, the environmental variables found to explain the variation in the responses best were used as covariates to remove their effect prior to further analysis. During the procedure, samples 10_{NU}, 57_{C} and 60_{C}, even though already weighted down, caused heavy bias. As a result, the samples had to be removed after all.

After controlling for the effect of the covariates, only eight of the soil parameters remained in the analysis. The significance test on the first axis showed no statistical significance. It follows that the hypothesis of a single dominating gradient determining the relation between response data and explanatory data has to be rejected (ter Braak & Šmilauer, 2012, p. 80). Of the partial variation left,18.02% ($7.45\%_{adj}$) are represented by the residual soil variables. The pH-value and the [C]:[N] ratio both explain just about 2% of the residual variation and constitute the most significant of the variables. Most of the variation is explained by the geological factors. One factor level, the humic Acrisols / humic Ferralsols, of the soil type variable was sustained. With 2.2% of the variation explained, the [Ca]:[Al] ratio was sustained in the analysis. When it comes to the ratio [Mg]:[Al], the contribution is fairly high as well.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.43	0.41	0.39	0.34	0.34
Explained variation (cumulative)	3.11	6.11	8.96	11.43	13.88
Pseudo-canonical correlation	0.95	0.87	0.94	0.90	0.94
Explained fitted variation (cumulative)	17.24	33.92	49.72	63.42	77.01

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
pH	2.2	5.4	1.6	0.001	0.00575
[C]:[N]	2.2	5.4	1.6	0.001	0.00575
Cat_Geol.SlateMylo	2.3	5.5	1.6	0.003	0.023
Soiltype_FAO.HAHF	2.2	5.4	1.6	0.005	0.02875
[Ca]:[Al]	2.2	5.3	1.6	0.006	0.01971
Cat_Geol.Sandstone	2.6	6.3	1.9	0.004	0.023
[Mg]:[Al]	2.4	5.8	1.8	0.015	0.04312
Cat_Geol.GranitePara	1.9	4.6	1.4	0.017	0.04888

Table 4.10 a, b: Results of a partial CCA using the soil parameters recorded as explanatory variables after removing the impact of the environmental parameters selected in the previous step. Partial variation is 13.75487. The explanatory variables account for 18.02% or $7.45\ \%_{adj}$ of the variation in the species data, respectively. See Annex 9 for VIFs.

Thus, the effect of the soil parameters revealed after stepwise forward selection amounts to the explanation of 12,56% ($5.19\%_{adj}$) from the original variation in the response data. Consequently, the explanatory power of the soil variables has almost been halved.[5]

With the further reduction of the number of soil parameters, the limitation to the drillable soil depth was left out as well as the geological categories quartzite and metaquartzite/shistic/complex with mainly Quartzite with shistic layer as well as the granitic rock/paragneiss/orthogneiss with inclusions of undifferentiated sediment rock, and finally the slate and mica slate with phyllonites and quarzitic inclusions of minor importance. Two soil types were left out of the model as well, the vertic luvisols/vertic cambisols and the humic acrisols/humic (ferralic) cambisols. The soil texture silty loam was also left out. During

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[5] Total variation refers to a model excluding samples 10NU, 57C and 60C as well. As to prove decomposition, an according CCA was conducted on the basis of the environmental variables determined by forward selection (the results of which are not shown). The model pertaining to the environmental variables displayed above is based on a different set of samples. The total variation and explained variation resulting from the interactive forward selection given for the soil parametres are not to be compared or put into relation.

the analysis, the geological factor level granite rock/paragneiss/orthogneiss has been included in the set of soil variables. Thus, it seems, though some of the soil parameters retained clearly depend on the climatic and landscape variables, the remaining impact is still of essence to species composition.

The graphs stemming from the analysis prove to be quite tricky in interpretation and require some lengthy explanations including some ifs and buts. Some of the statements given in the interpretation of the analyses above have already exemplified this. Since TER BRAAK & ŠMILAUER (2012, p. 228) have stated that "[…] especially when the biplot represents only a small part of the variation […]" "[i]nferences from the biplot may be in error […]," we will, therefore, not take a look at the corresponding graphs here.

Since the number of explanatory variables has been greatly reduced, the drop in the amount of variation explained does not come as a surprise. It has to be considered that not only explanatory variables have been left out of the model, but quite a large amount of multicollinearity has also been removed. Thus, the information retained is more reliable despite the sometimes low statistical significance after adjustment for multiple testing, and the loss of information may be acceptable.

As has already been suspected, the environmental parameters wield some impact over the soil parameters. It has already been stated that the [Mg], [Ca] and [Al] are impacted by climate. Though the concentrations of the metals themselves do not seem to have much of an impact, it is the ratios among them which may contain information as to the composition of species of the pertinent vegetation. Consequently, the findings are much the same as those found with respect to the [C]:[N] ratio. It also has to be noted that even after removing samples 57_C and 60_C, both having extreme values here, the ratios continued to have an impact even beyond the partial analysis.

So, the environmental variables do impact soil conditions, and this also means that some of the variation explained by the environmental variables is mediated through the soil, i.e., there are indirect environmental impacts. What is left of pure environmental impact after partialling out the chosen soil parameters?

In order to answer this question, tables have been turned, and soil parameters have been given the status of covariables. It has to be noted here that the procedure, as implemented in Canoco 5, does not allow for the selection of individual states of a factor variable for inclusion as a covariate. Thus, because the group is now larger, a somewhat increased amount of variation is partialled out by the covariates. After interactive forward selection of the explanatory variables, only six of the environmental parameters remained. First, inclination dropped out of the analysis. Several states of the forest matrix were left out as well. It appears that the samples taken close to the visitors' complex at Uwinka are somewhat impacted in species composition as well as the ones adjacent to an earth road right through the forest. What has also been left out is the impact of the positioning in reference to the watershed dividing Nyungwe National Park. The remaining environmental variables, though the respective statistical significances decreased, show almost the same amount of impact upon species variation. Variance inflation factors do not exceed 6.33 (Annex 9).

The variation explained by the environmental variables without the impacts moderated via the soil, amounts to 10.43% (3.85%$_{adj}$). The variation explained by the covariates stems from 17 DF. Since this is almost double what has been established after determining the most pertinent soil variables, interpretation has to progress with care. In other words, too many of the environmental variables may have been excluded. If the alpha level had not been based on the adjusted p-values, the matrix state through road earth could have been included.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.37	0.31	0.27	0.27	0.19
Explained variation (cumulative)	2.73	5.01	7.04	9.04	10.43
Pseudo-canonical correlation	0.87	0.88	0.84	0.87	0.74
Explained fitted variation (cumulative)	26.16	47.99	67.53	86.65	100.00

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
Elev_a_ s_l m	2.2	6.4	1.6	0.004	0.021
NEAR_DIST	2.2	6.7	1.7	0.002	0.028
Matrix.TreePlnt	2	6	1.5	0.008	0.042
Matrix.Uwinka	2	6.1	1.5	0.009	0.04725
Precip_a mm	2	6	1.5	0.012	0.0504

Table 4.11 a, b: Results of a partial CCA using the environmental parameters recorded as explanatory variables after removing the impact of the soil parameters selected in the previous step. Partial variation is 13.43499. The explanatory variables account for 10.43% or 3.85 %$_{adj}$ of the variation in the species data, respectively. See Annex 10 for VIFs.

During the above analyses two models have been established, highlighting the impact of environmental variables not related to soil and the impact of soil parameters. Both models are developed on different foundations. The environmental model is based on the exclusion of one sample and the down weighting of two further samples. The soil model is based on the exclusion of three of the samples. These differences leave two results which can only be connected to each other in a quite laborious way. On the other hand, the singular impacts of the states of the factor variables are resolved; an option that is not readily available in the next analysis step. Here, the variation explained will be partitioned between the environmental and soil parameters within the same model. The variation likely to be generated jointly by them will also be elucidated.

4.2.3.2 Variation Partitioning

The variation partitioning analysis template, as provided by Canoco 5 using two groups of explanatory variables and testing for conditional effects, was employed. Since the contribution of the variables has been illuminated above, interactive stepwise forward selection was postponed for the time being. The sequence of the groups is not of importance since the analysis template provides reciprocal testing to disentangle the simple effects of the respective variable groups.

Thus, the first group comprises the environmental variables as in Table 4.12, with the exclusion of inclination.[6] The second group comprises the soil variables as in Table 4.12. Note however, that only the inclusion of complete factor variables is possible, not just the inclusion of single factor levels. This necessity resulted in elevated variance inflation factors

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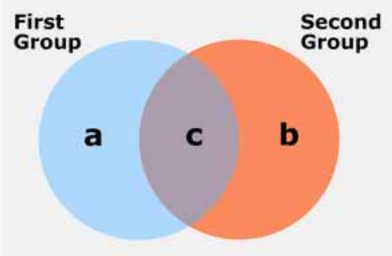
[6] In an interactive forward selection attempt inclination was still included. No noteworthy increase in explanatory power was noticed. Since variance inflation factors increased, inclination was left out in order to achieve more reliable results.

and, consequnetly, adds some uncertainty to the results. The variation explained has been adjusted, however, by the method given in Peres-Neto et al. (2006).

The model results in an adjusted variation of 5.30% , which is explained by the environmental variables alone, i.e., the sole impact after accounting for soil parameters. At the same time, these alone explain 11.30% of the variation in the response variables. The joint impact amounts to 4.70%, leaving the total explained variation at an adjusted 21.30% (see Table 4.12).

Fraction	Variation(adj)	% of Explained	% of All	DF	Mean Square
a	1.04	24.70	5.30	19.00	0.22
b	2.24	53.20	11.30	17.00	0.28
c	0.93	22.10	4.70	--	--
Total Explained	4.21	100.00	21.30	36.00	0.29
All Variation	19.735	--	100	90	--



Group Members:	
First Group	Second Group
Precip_a mm	Ca_Al
Elev_a_ s_l m	Mg_Al
NEAR_DIST	Soiltype_FAO
Matrix	C_N
Congo_Nile	pH
	Cat_Geol

Tested Fraction	F	P
a+b+c	1.7	0.001
a	1.3	0.004
b	1.6	0.001

Table 4.12 a - c: Results of a variation partitioning approach based on CCA. The environmental parameters and the soil parameters recorded were employed to set up the groups. The upper table contains the explanatory power of the fractions. The table on the right displays the explanatory variables contained in the respective group. The table below the Venn diagram contains the statitistical significances after Monte Carlo permutation. The Venn diagramm is used to illustrate the groups and the fractions of explained and unexplained variation. Remember: Fraction c is not an interaction term. This common fractions represents the correlation of explanatory variables in the two sets. See Annex 11 for VIFs.

From a biplot of axes one and two it can be seen that the elevation a.s.l., [C]:[N] ratio and [Ca]:[Al] ratio exert the most influence (Fig. 4.38 A). While the same elevational stratification of the sample sites—as with indirect ordination—can be observed, the separation of the samples from Mt Bigugu and from Mt Muzimu along the respective vectors seems overemphasised and somewhat in error; particularly because the samples from Mt Bigugu are, on average, from higher altitudes and the [C]:[N] ratios are comparable. Since canonical ordination reflects the variations and relations within the data as weight averages, the distances between the samples are due to other variables as well. In the case of Mt Bigugu and Mt Muzimu, the soil type is of importance. While the humic acrisols/humic ferralsols are mainly found on Mt Muzimu, the dystric regosols/dystric leptosols found in most of the plots on Mt Bigugu are more widely spread. The centroid principle on the basis of which the levels of factor variables are positioned in the plot, causes said centroids to be placed in relation to the other explanatory variables as well; hence, influencing the positioning of the samples from Mt Bigugu and Mt Muzimu.

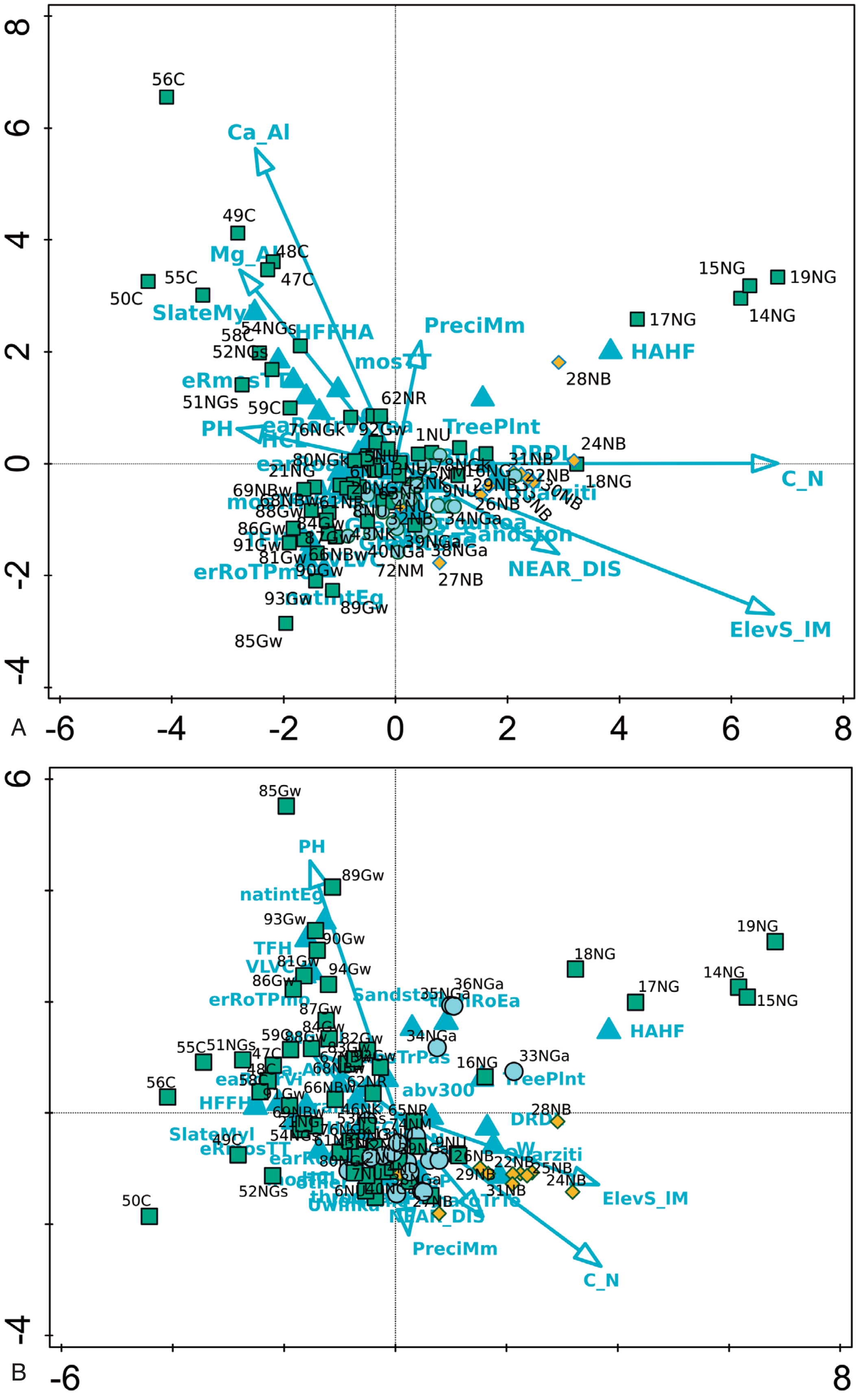


Figure 4.38 A, B: Biplots of axes one and two (A) and one and three (B). The variation partitioning procedure was based on CCA. Hill scaling was used to establish the axes.

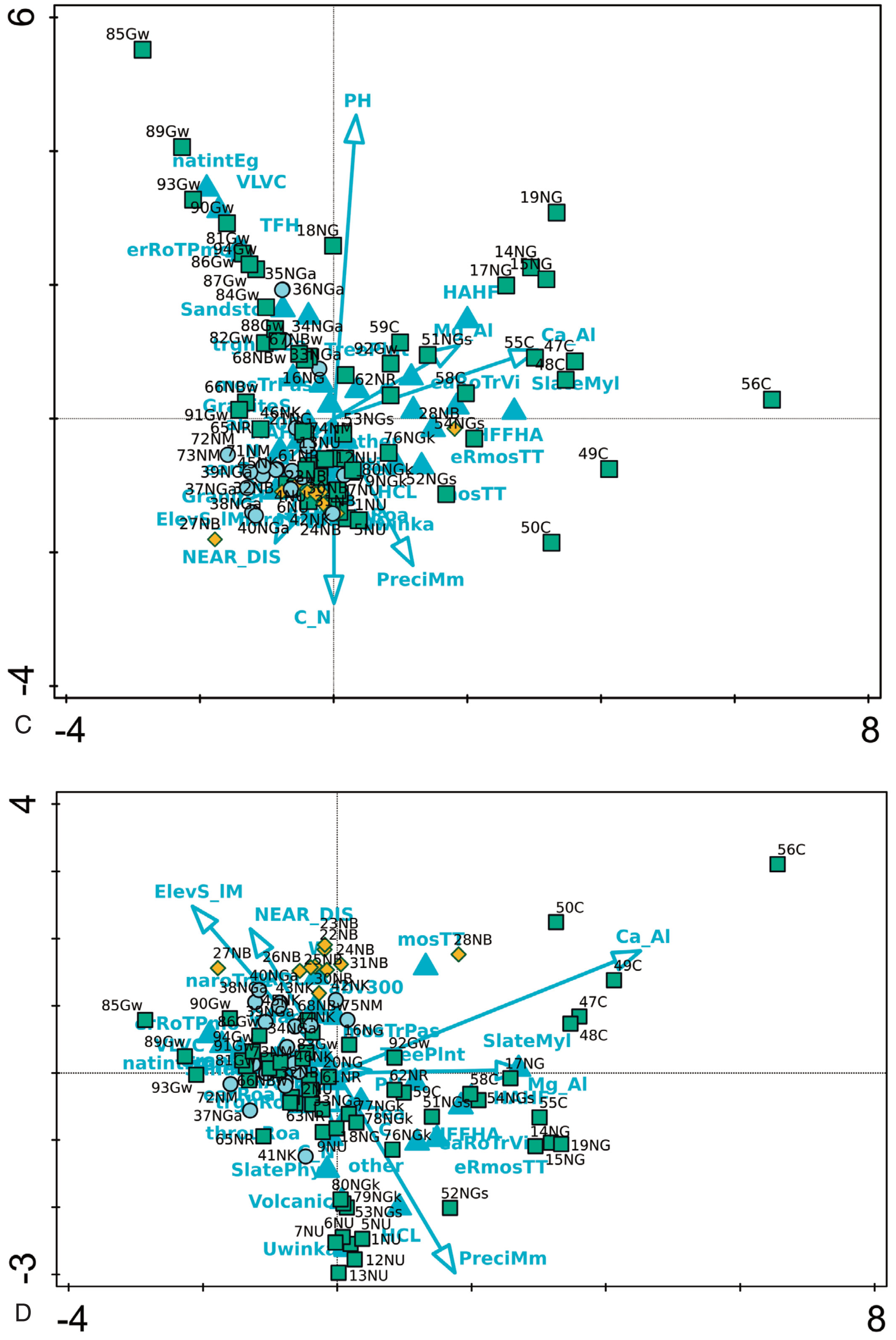


Figure 4.38 C, D: Biplots resulting from variation partitioning based on CCA. C depicts axes two and three. D depicts axes two and four. For further explanations, see the text.

Two other major impacts are visible here. The [Ca]:[Al] and the [Mg]:[Al] ratios are separating the samples from Cyamudongo Forest from most of the other samples. Thus, the segregation of the forest remnant is due not only to elevation a.s.l., lower [C]:[N] ratios and, on average, elevated pH values. The same is true for some samples from around Gasumo just east of Cyamudongo on the western border of Nyungwe Forest. Here again, the ordination plot might be misleading at first glance. Though sample 51_{NGs} exhibits the same increased ratios, the other samples from Gasumo do not. Most of the samples feature quite low [C]:[N] ratios and are situated close to an earth road accompanied by a mosaic of tree and tea plantations at the fringe of the forest. At this point, the relation between pH value, [C]:[N] ratio and both [Al] related ratios must not be forgotten. Of smaller impact, mean annual precipitation divides the samples along the second axis. This relationship can be observed better in a plot of axes two and four (Fig. 4.38 D). This plot, however, is a false representation of elevation above sea level for the two groups of samples. The samples from Uwinka are, on average, situated at higher altitudes then the Gishwati samples. Although the separation along the gradient in pH values in a plot of axes one and three does not correctly depict the relations among the Gishwati samples, it shows the overall segregation of all samples quite well. The relatively low [C]:[N] ratios in Gishwati Forest are accompanied by quite high pH values. With changed signs, this holds true for the samples from Mt Bigugu and Mt Muzimu. Likewise, the samples from the Nile side of the watershed are set apart here.

In summary, no new insights have been gained here. The results have been refined by eliminating several explanatory variables, be it environmental or soil parameters. It has also been elucidated that not all of the factor levels exert the same impact. This level of resolution had to be partly abandoned, however, due to the limitations of the methods available. These limitations also resulted in increased variance inflation factors giving clear information about collinearities. An example is the distance to the forest margin. While stripped of several factor levels, multicollinearity was kept below a value of ten. With all factors included, some straight correlation between the environmental variables is present. Nevertheless, the distance to the forest margin has significant impact. Another result not found by indirect ordination is the impact upon the response variables exerted jointly by environmental and soil variables. Here, the effect of the [C]:[N] ratio was retained as one of the most influential factors. At first glance the comparatively larger impact of soil parameters may come as a surprise. Barely, if at all visible, some of the intermixture between the samples from the different positions to the watershed has been recovered despite the constrained ordination as well.

4.2.4 Redundancy Analysis

While the separated analyses of the environmental and soil parameters produced somewhat clear results, the cumbersome interpretation of the joint plots and the low percentage of variation explained, raised the question as to the adequacy of CCA. (see 2.6) The unimodal response in the data appears obvious, but it does not seem to be solely at work. Hence, RDA has been applied as well along the scheme previously used with CCA. Since the linear method is not appropriate for the data at hand, the modifications and transformations given under 2.6 were used to adapt the method to the data. In the battle for clarity, the decision concerning the in- or exclusion of an explanatory variable was dictated by minimising collinearity whilst keeping the loss of information at bay. Before we turn towards the Hellinger transformation-based approach, the results of distance-based RDA will be displayed. As has been stated, variation partitioning is only available on the basis of RDA, not db-RDA. At the end of this analysis, variation partitioning will be carried out. Accordingly, comparability between the results stemming from db-RDA and the partitioning approaches based on tb-RDA is limited.

4.2.4.1 Distance-Based Redundancy Analysis

Distance-based redundancy analysis with interactive stepwise forward selection based on environmental variables alone gave an explained variation of 31.28% (23.00%$_{\text{adj}}$). This analysis includes the usual parameters, with elevation being the most prominent. Most of the levels of the forest matrix included feature roads. The values and variables are shown in Table 4.13 a,b.

The same procedure taking only the impact of soil parameters into account gave a total variation explained of 39.27% (27.60%$_{\text{adj}}$). Except for including more states of the usual factor variables, some additional soil parameters were chosen. The limitation of the drillable soil depth caused by stone was also recognised here. New is the addition of the [Al] itself, while only the [Mg]:[Al] was maintained (see Tab. 4.14 a - b).

Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.08	0.07	0.05	0.03
Explained variation (cumulative)	8.46	15.83	21.28	24.27
Pseudo-canonical correlation	0.83	0.95	0.83	0.77
Explained fitted variation (cumulative)	27.04	50.59	68.01	77.59
Pseudo-canonical correlation (suppl.)	0	0	0	0

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
Elev_a_ s_l m	6.4	11.7	6.3	0.001	0.00292
NEAR_DIST	4	7.3	4.1	0.001	0.00389
Congo_Nile.N	4	7.3	4.2	0.001	0.00389
Matrix.Uwinka	3.6	6.5	3.9	0.001	0.00389
Precip_a mm	3.1	5.6	3.5	0.001	0.00389
Matrix.throuRoa	2.9	5.4	3.4	0.001	0.00389
Congo_Nile.W	2.2	4	2.5	0.001	0.0035
Congo_Nile.C	2.2	4	2.5	0.001	0.0035
Matrix.earRoaTree	2	3.7	2.4	0.001	0.00389
Matrix.trghRoEa	1.5	2.8	1.8	0.008	0.028
Matrix.TreePlnt	1.5	2.8	1.8	0.006	0.021

Table 4.13 a, b: Results of a db-RDA based on the environmental parameters as explanatory variables. Table B contains the remaining explanatory variables after interactive stepwise forward selection. See Annex 12 A for VIFs.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.09	0.07	0.06	0.04
Explained variation (cumulative)	9.44	16.26	21.80	25.41
Pseudo-canonical correlation	0.88	0.92	0.82	0.83
Explained fitted variation (cumulative)	24.04	41.41	55.52	64.69
Pseudo-canonical correlation (suppl.)	0	0	0	0

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
[C]:[N]	5.9	9	5.8	0.001	0.00272
pH	3.1	4.7	3.1	0.001	0.00258
Cat_Geol.Quarzitic	5.7	8.6	6	0.001	0.00288
Cat_Geol.SlateMylo	4.5	6.8	4.9	0.001	0.0049
Cat_Geol.SlatePhyllo	3.6	5.5	4.1	0.001	0.00544
Soiltype_FAO.HAHF	2	3	2.3	0.001	0.0049
Cat_Geol.GranitePara	2	3	2.3	0.001	0.00613
Cat_Geol.GraniteSedi	1.7	2.6	2	0.002	0.00817
Cat_Geol.Volcanic	1.7	2.6	2	0.001	0.00445
Cat_Geol.Sandstone	1.7	2.6	2	0.001	0.00445
[Mg]:[Al]	1.6	2.4	1.9	0.002	0.007
Soiltype_FAO.VLVC	1.5	2.2	1.8	0.006	0.01633
Soiltype_FAO.DRDL	1.4	2.2	1.8	0.007	0.02018
Limitation.stone	1.9	2.9	2.4	0.001	0.0049
[Al]	1.3	2	1.7	0.008	0.02306
Soil_text.Lu	1.4	2.1	1.8	0.005	0.0175

Table 4.14 a, b: Results of a db-RDA with interactive forward selection based on the soil parameters as explanatory variables. See Annex 12 B for VIFs.

Both of the above analyses have been carried out in their partial form to account for the sole impact of the respective explanatory variables; one attempt each with the respective other parameters as covariates. While the variation explained was reduced as expected, variance inflation factors increased. In the case of the environmental variables, the increase was not tolerable. Utilising the same partial idea, though this time with a new forward selection, reduced VIF greatly. With the groups of explanatory variables now smaller, the explained variation decreased likewise. The exclusive impact of environmental variables as described by Table 4.15 amounts to 18.49% (9.60%$_{adj}$) of the variation in the species data. With the soil variables as explanatory variables, the remaining impact amounts to 27.31% (14.41%$_{adj}$) after accounting for the environmental variables (see Tab. 4.16). Removal of the samples causing heavy bias in CCA brought about neither an improvement of explanatory power nor improved interpretability of the graphs.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.03	0.02	0.01	0.01
Explained variation (cumulative)	5.63	9.71	12.71	15.43
Pseudo-canonical correlation	0.84	0.79	0.82	0.78
Explained fitted variation (cumulative)	30.47	52.53	68.75	83.47
Pseudo-canonical correlation (suppl.)	0	0	0	0

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
Elev_a_ s_l m	2.9	6.8	1.8	0.014	0.04
NEAR_DIST	3.1	7.2	1.9	0.007	0.02333
Precip_a mm	3.3	7.7	2.1	0.002	0.01
Matrix.Uwinka	4.2	9.8	2.8	0.001	0.02
Matrix.mosTrPas	2.7	6.3	1.8	0.01	0.05
Congo_Nile.N	2.3	5.5	1.6	0.014	0.04667

Table 4.15 a, b: Results of a partial db-RDA with interactive forward selection based on the environmental parameters as explanatory variables. See Annex 13 A for VIFs.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.03	0.02	0.02	0.01
Explained variation (cumulative)	5.54	9.43	12.69	15.17
Pseudo-canonical correlation	0.81	0.84	0.88	0.73
Explained fitted variation (cumulative)	20.28	34.51	46.48	55.55

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
[C]:[N]	3.4	4.8	2.5	0.001	0.00625
pH	2.8	4	2.1	0.002	0.0125
Cat_Geol.Quarzitic	2.9	4.1	2.3	0.001	0.01667
Cat_Geol.SlateMylo	2.7	3.8	2.1	0.002	0.01667
Soiltype_FAO.HAHF	2.4	3.4	1.9	0.002	0.01667
Cat_Geol.GranitePara	2.4	3.5	2	0.001	0.01667
Cat_Geol.Volcanic	2.1	3	1.7	0.004	0.02857
Limitation.stone	2.1	3	1.7	0.007	0.04375
Soiltype_FAO.HAHFC	2	2.9	1.7	0.009	0.04091
[Ca]:[Al]	2	2.9	1.7	0.011	0.05
Soil_text.Lu	2.4	3.3	2	0.001	0.0125

Table 4.16 a, b: Results of a partial db-RDA with interactive forward selection based on the soil parameters as explanatory variables and the environmental variables as covariables. The lower table contains the soil parameters remaining after controlling for covariate effects and interactive stepwise forward selection. See Annex 13 B for VIFs.

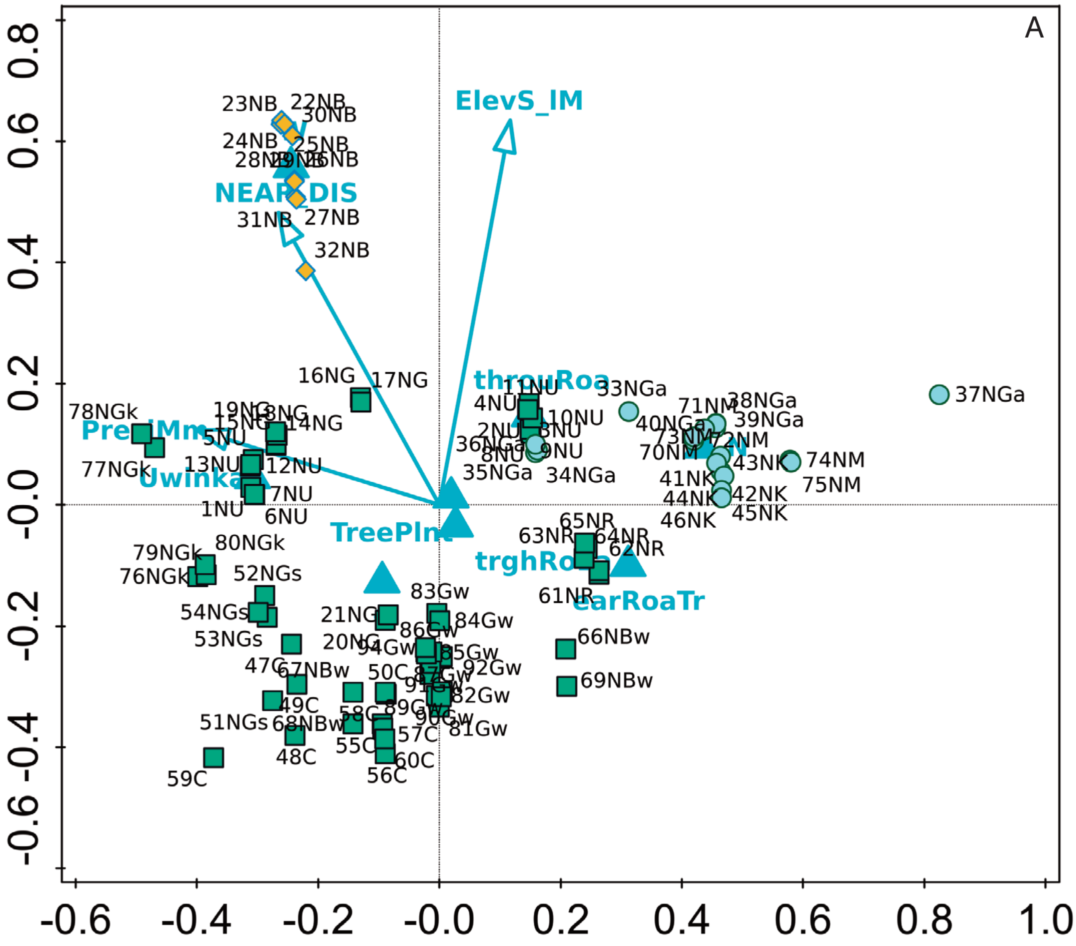


Figure 4.39 A: Biplots resulting from a db-RDA utilising the environmental variables as explanatory variables. The symbols for the samples are coded by colour. The green squares represent the samples from the Congo side of the watershed. The samples from the Nile side are depicted as light blue circles. Orange rhombuses symbolise the samples directly on the watershed. For further explanations, see the text.

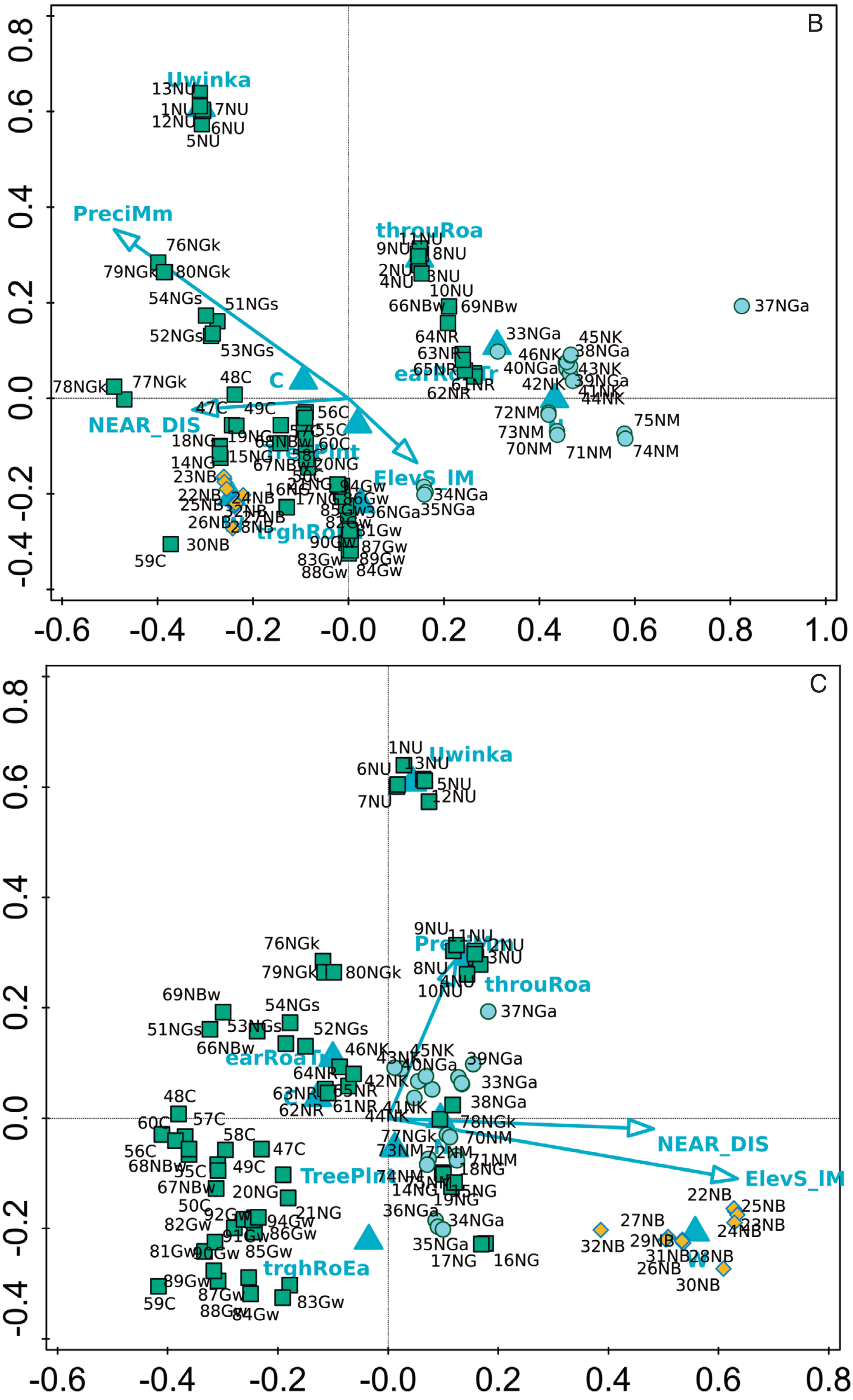


Figure 4.39 B and C: Biplots resulting from a db-RDA utilising the environmental variables as explanatory variables. For further explanations, see the text.

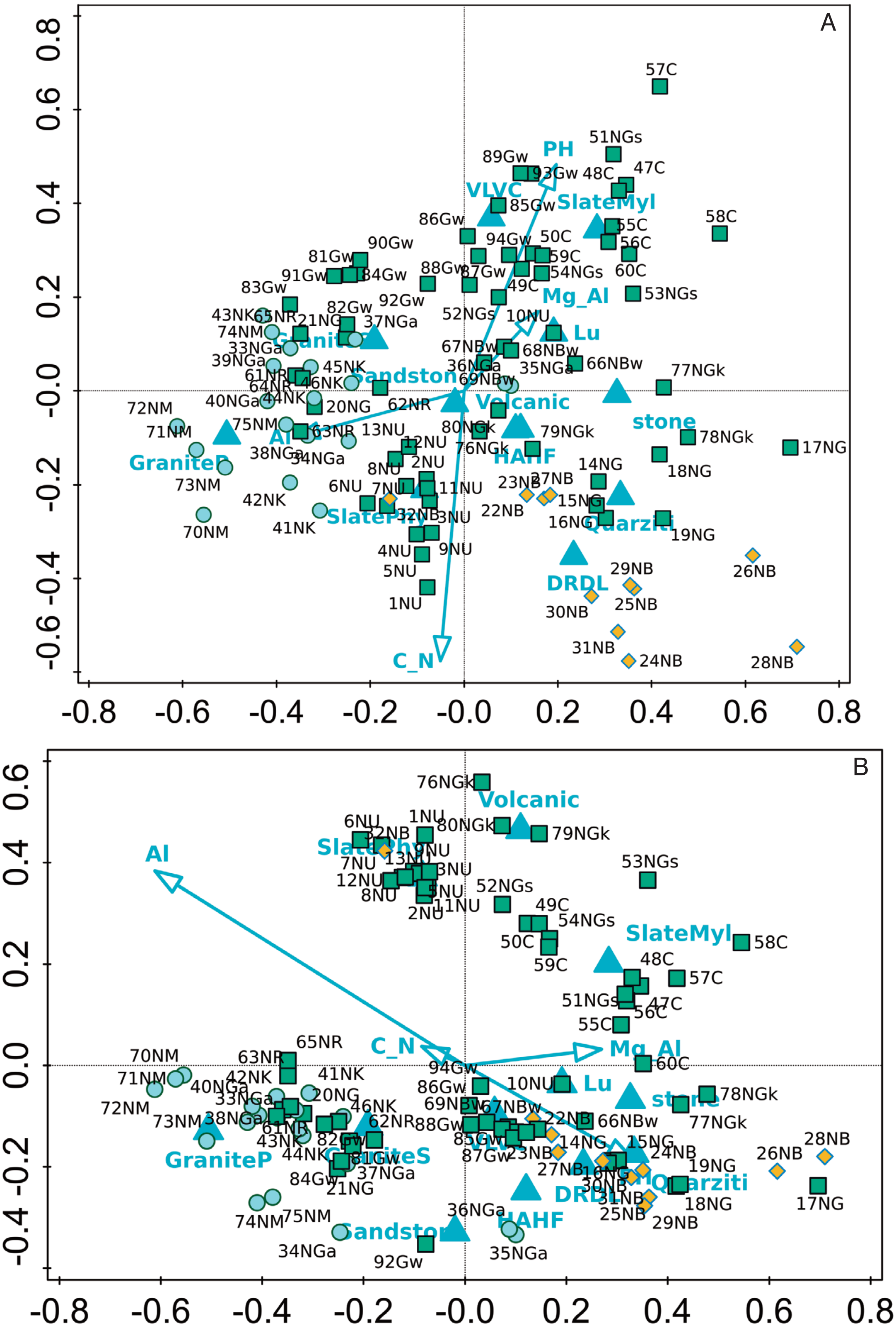


Figure 4.40 A and B: Biplots resulting from a db-RDA utilising the soil variables as explanatory variables. The symbols for the samples are coded by colour. The green squares represent the samples from the Congo side of the watershed. The samples from the Nile side are depicted as light blue circles. Orange rhombuses symbolise the samples directly on the watershed. For further explanations, see the text. (Pane A: axes one and two; Pane B axes one and three)

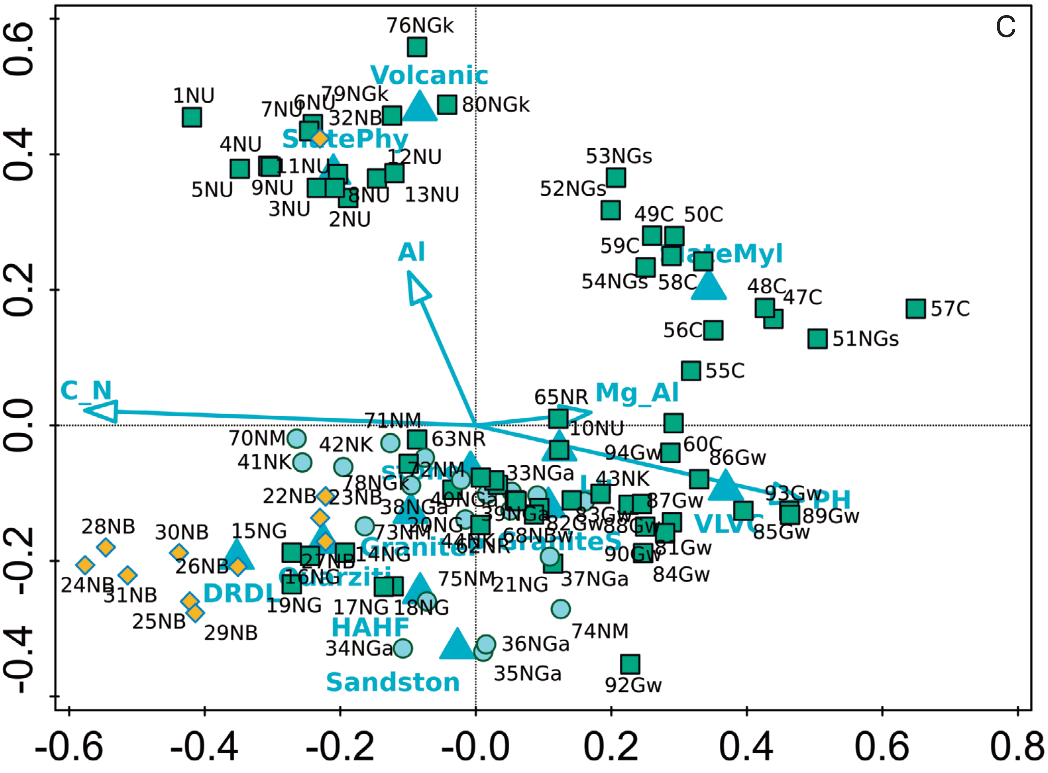


Figure 4.40 C: Biplot (Axes 2 & 3) resulting from a db-RDA utilising the soil variables as explanatory variables.

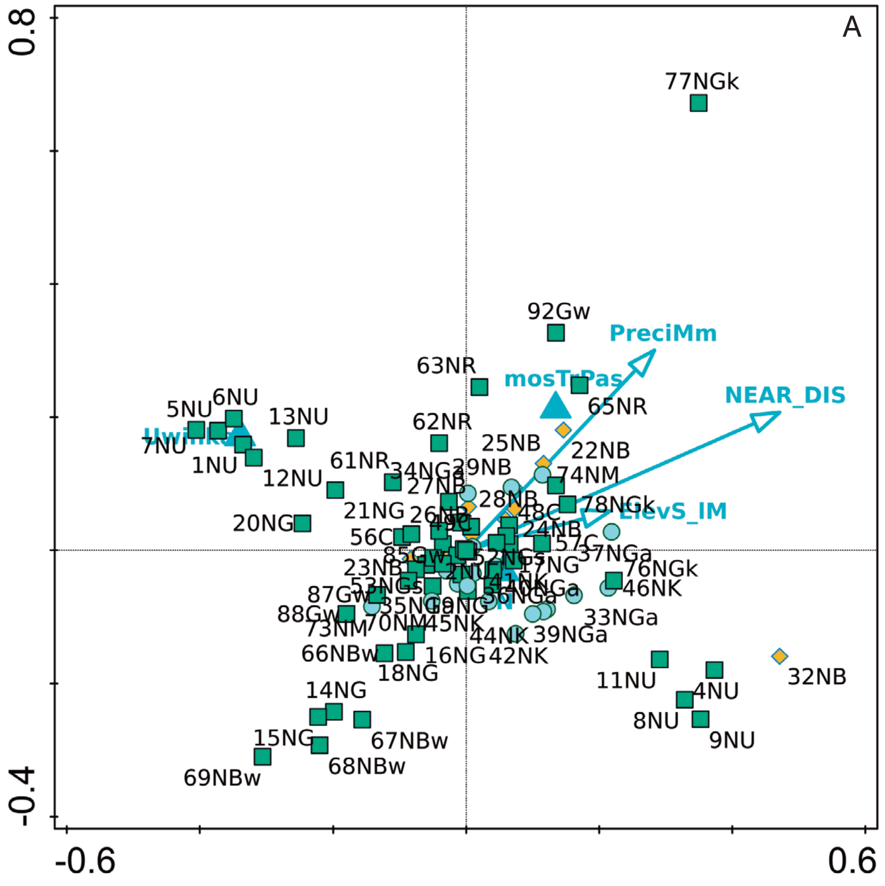


Figure 4.41 A: Biplot of axes one and two resulting from a db-RDA utilising the environmental factors in the explanatory role after removing the effect of the soil variables.

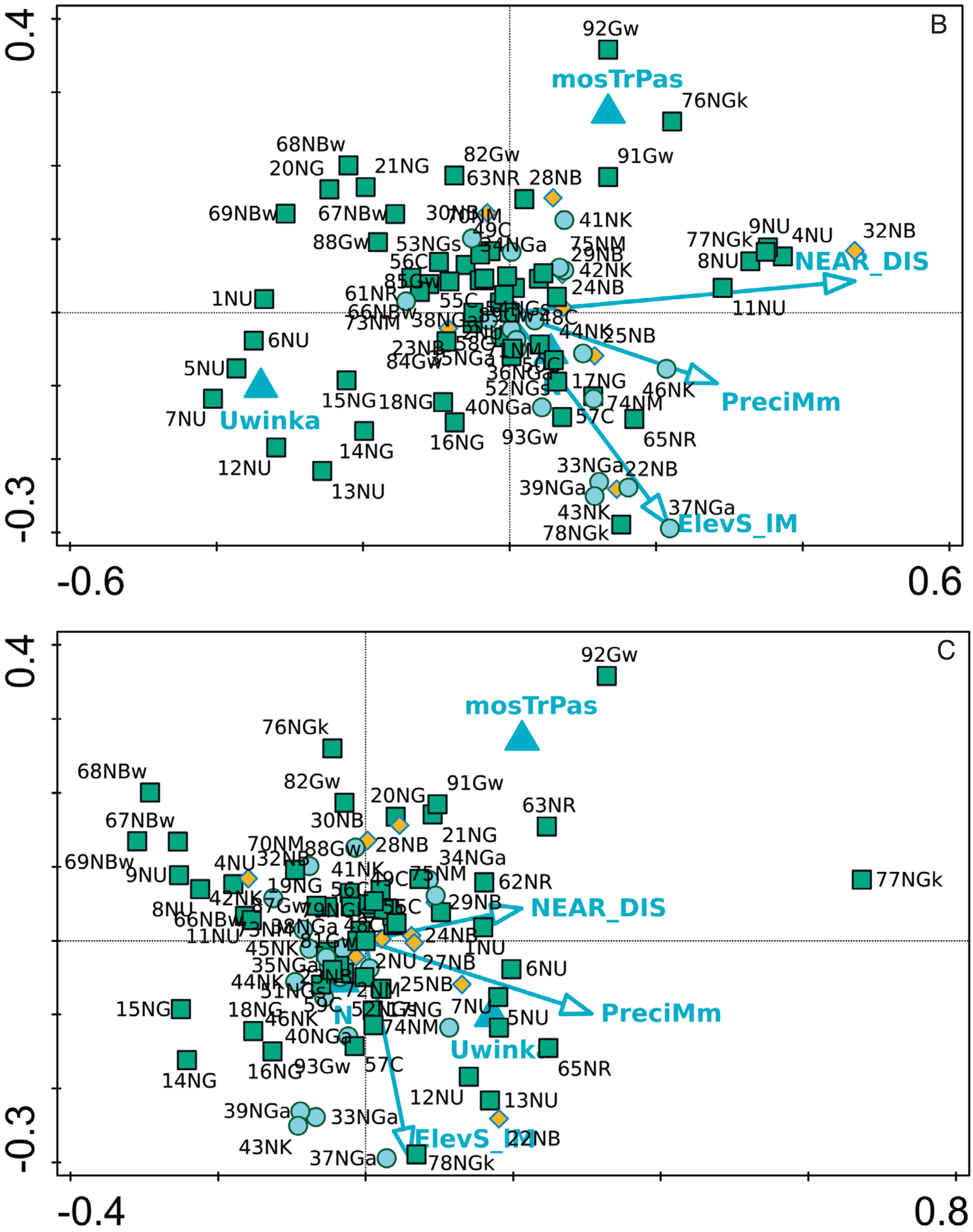


Figure 4.41 B and C: Biplots of axes one and three (B) and two and three (C), respectively. A db-RDA utilising the environmental factors in the explanatory role after removing the effect of the soil variables was run. For further information see the text above.

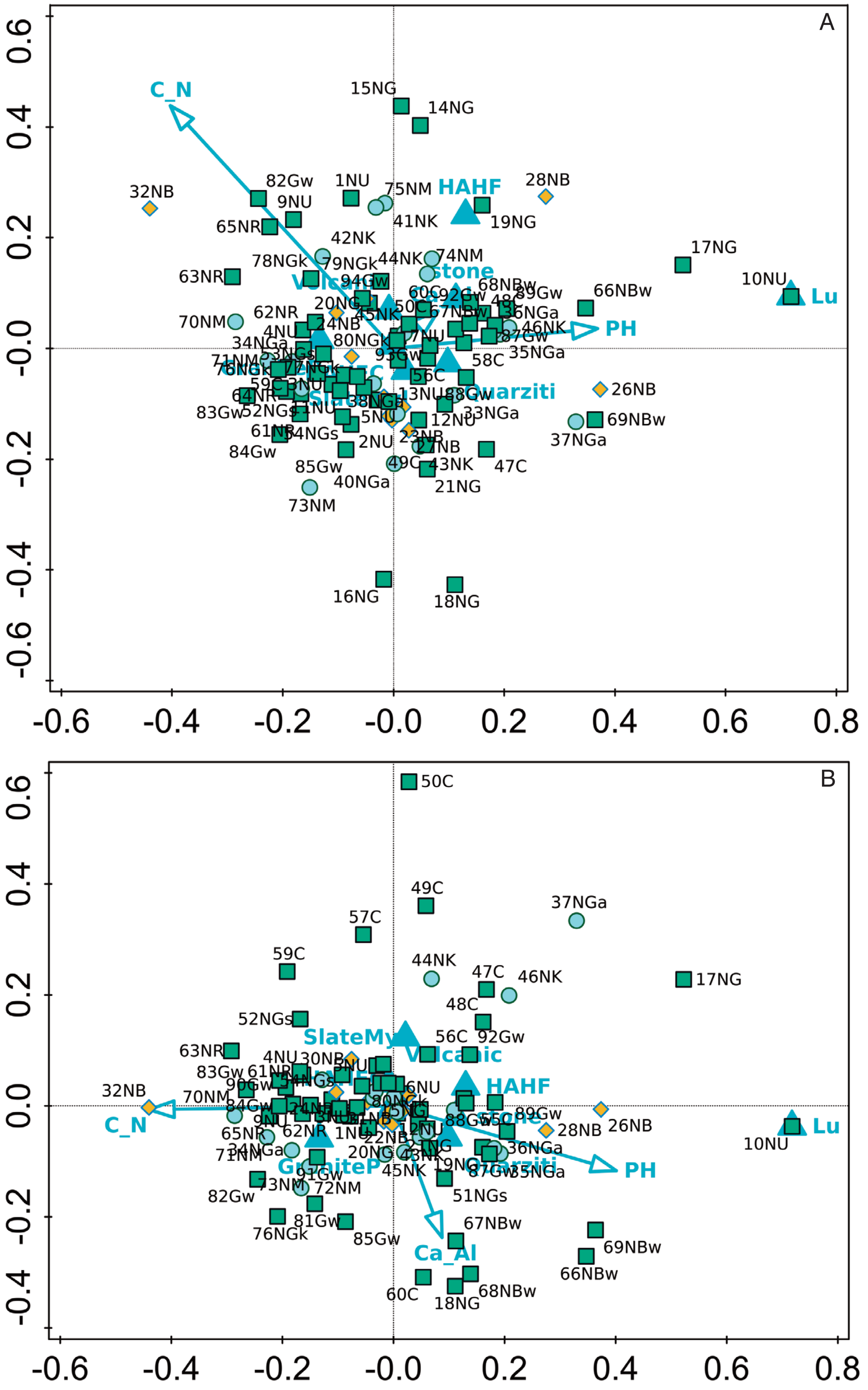


Figure 4.42 A and B: Biplots stemming from partial db-RDA. Pane A: axes 1 and 2; Pane B axes 1 and 3.

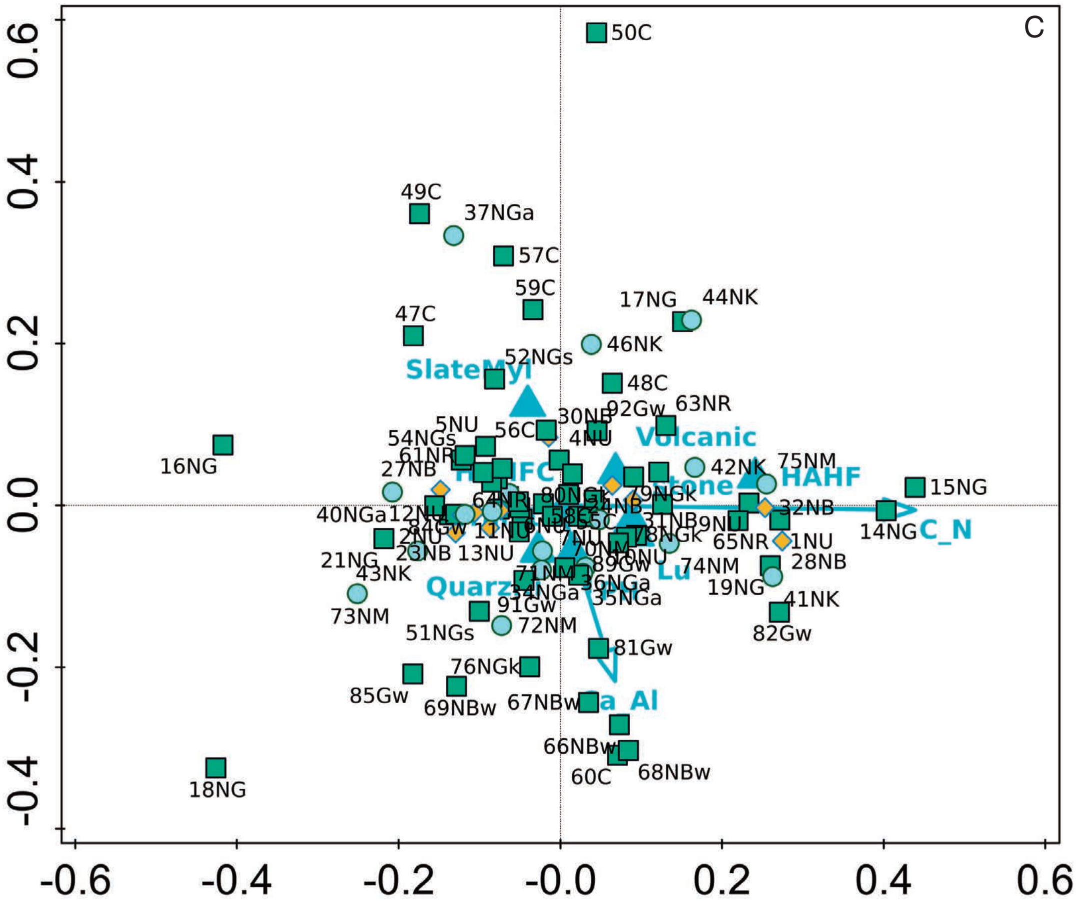


Figure 4.42 A to C: Panes A and B can be found on page 282. Biplots of axes one and two (A) one and three (B) as well as two and three (C), respectively. A db-RDA utilising the soil factors in the explanatory role after removing the effect of the environmental variables was carried out. For further information see the text above.

After the exploration of the unique effects of each group of impact variables, the focus is now set on the joint impact and interpretation of the results. In order to achieve this objective, RDA has been employed. Since db-RDA focuses on community composition, and a model of the relation of the response variables with the constrained ordination axes cannot be obtained directly, RDA based on Hellinger transformation (2.6.2.2) was used to adapt the method to the data type.

4.2.4.2 Transformation-Based Redundancy Analysis

The scheme used followed the one established above, starting with the single impacts of the variable groups, through the partial partial effects, to the variation partioning analyses.

The first approach, based on environmental variables alone, gave an explained variation of 30.17% (20.81%$_{adj}$) after interactive forward selection. The set of explanatory variables chosen is not much different from CCA. The same is valid for the soil variables. Here 36.63 % (24.44 %$_{adj}$) have been explained by the interactively selected variables.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.08	0.06	0.05	0.03	0.02
Explained variation (cumulative)	7.90	14.22	19.12	21.91	23.90
Pseudo-canonical correlation	0.83	0.94	0.85	0.78	0.76
Explained fitted variation (cumulative)	26.18	47.13	63.36	72.62	79.19

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
Congo_Nile.W	5.5	10.3	5.4	0.001	0.003
NEAR_DIST	2.2	4.1	2.2	0.005	0.01636
Elev_a_ s_l m	4.3	8.1	4.4	0.001	0.004
Precip_a mm	3.2	5.9	3.3	0.001	0.006
Congo_Nile.N	3.7	6.8	4	0.001	0.006
Congo_Nile.C	3.7	6.8	4	0.001	0.006
Matrix.Uwinka	2.7	5	3	0.001	0.0045
Matrix.throuRoa	2.2	4	2.4	0.001	0.00514
Matrix.earRoaTree	2	3.7	2.3	0.001	0.0045
Matrix.trghRoEa	1.6	2.9	1.8	0.005	0.018
Matrix.TreePlnt	1.5	2.8	1.7	0.005	0.01636
Matrix.eRmosTT	1.4	2.6	1.6	0.004	0.015

Table 4.17 a, b: Results of a tb-RDA with interactive forward selection based on the environmental parameters as explanatory variables. The lower table contains the environmental parameters remaining after interactive stepwise forward selection. The total variation is 79.70868, the explanatory variables account for 30.17% or 20.81%$_{adj}$. For VIFs see Annex 14 A.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.08	0.06	0.05	0.04	0.03
Explained variation (cumulative)	8.44	14.10	18.83	22.43	25.25
Pseudo-canonical correlation	0.85	0.91	0.82	0.86	0.82
Explained fitted variation (cumulative)	23.05	38.49	51.42	61.24	68.94

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
[C]:[N]	5.1	7.9	4.9	0.001	0.00276
pH	2.9	4.5	2.9	0.001	0.00276
Cat_Geol.Quarzitic	5.3	8.2	5.5	0.001	0.00336
Cat_Geol.SlateMylo	3.9	6	4.2	0.001	0.0047
Cat_Geol.SlatePhyllo	3.2	5.1	3.6	0.001	0.00522
Soiltype_FAO.HAHF	1.9	3	2.1	0.001	0.0047
[Mg]:[Al]	1.6	2.6	1.9	0.004	0.01343
Cat_Geol.GranitePara	1.9	2.9	2.2	0.001	0.0047
Limitation.stone	1.8	2.9	2.1	0.001	0.00427
Soiltype_FAO.VLVC	1.7	2.6	2	0.001	0.00427
Cat_Geol.Volcanic	1.7	2.6	2	0.001	0.00392
Cat_Geol.Sandstone	1.6	2.5	1.9	0.001	0.00362
Cat_Geol.GraniteSedi	1.6	2.5	1.9	0.001	0.00362
Soiltype_FAO.HAHFC	1.4	2.1	1.6	0.008	0.02212
Soiltype_FAO.HFFHA	1.3	2	1.6	0.011	0.03041
Soiltype_FAO.HCL	1.4	2.2	1.8	0.002	0.00671

Table 4.18 a, b: Results of a tb-RDA with interactive forward selection based on the environmental parameters as explanatory variables. The lower table contains the environmental parameters remaining after interactive stepwise forward selection. The total variation is 79.70868, the explanatory variables account for 36.63% or 24.44%$_{adj}$. For VIFs see Annex 14 B.

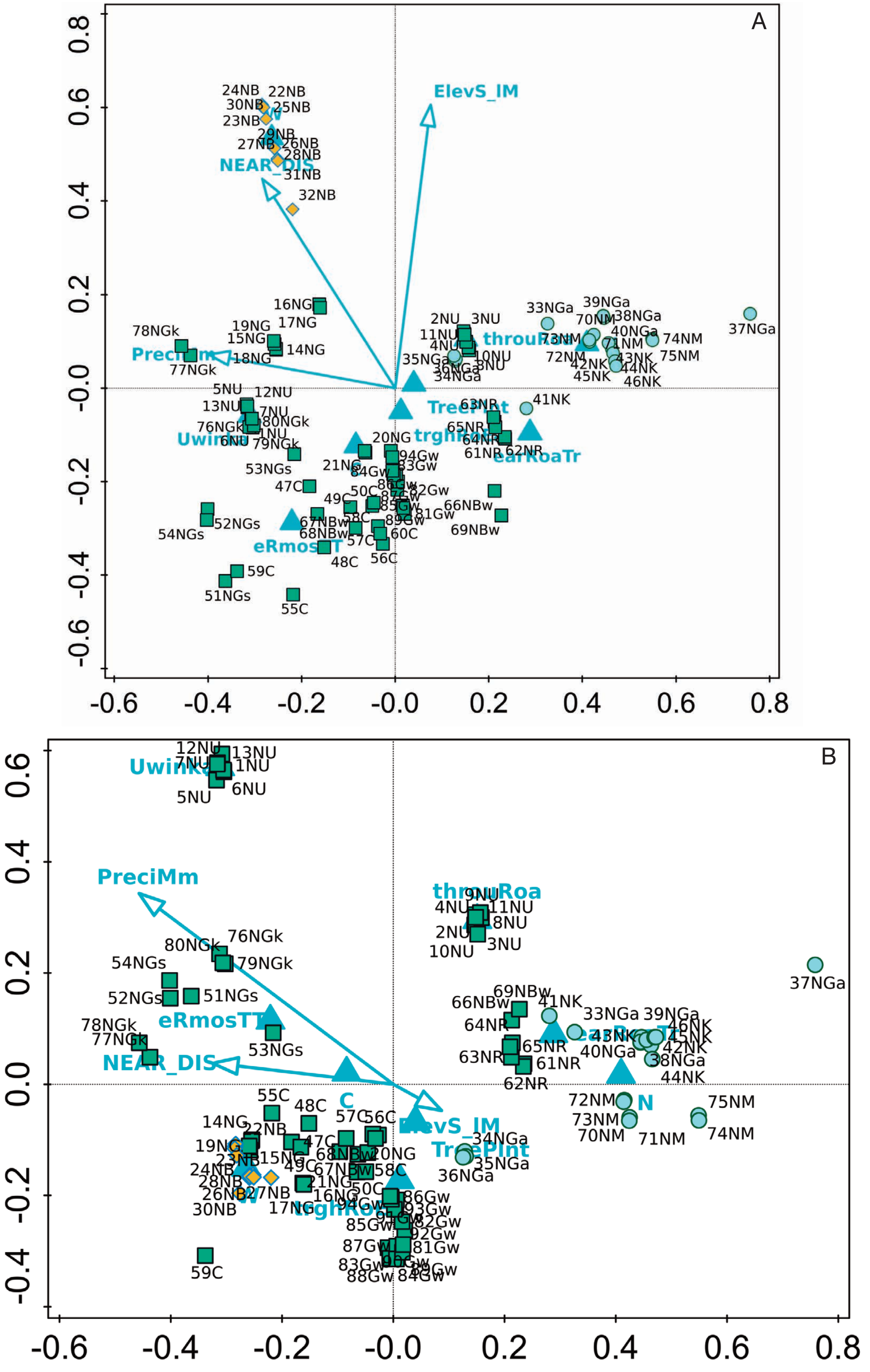


Figure 4.43 A to C: See top of page 286 for pane C. Biplots of axes one and two (A) and one and three (B), respectively. Results of a tb-RDA with the environmental factors as explanatory variables.

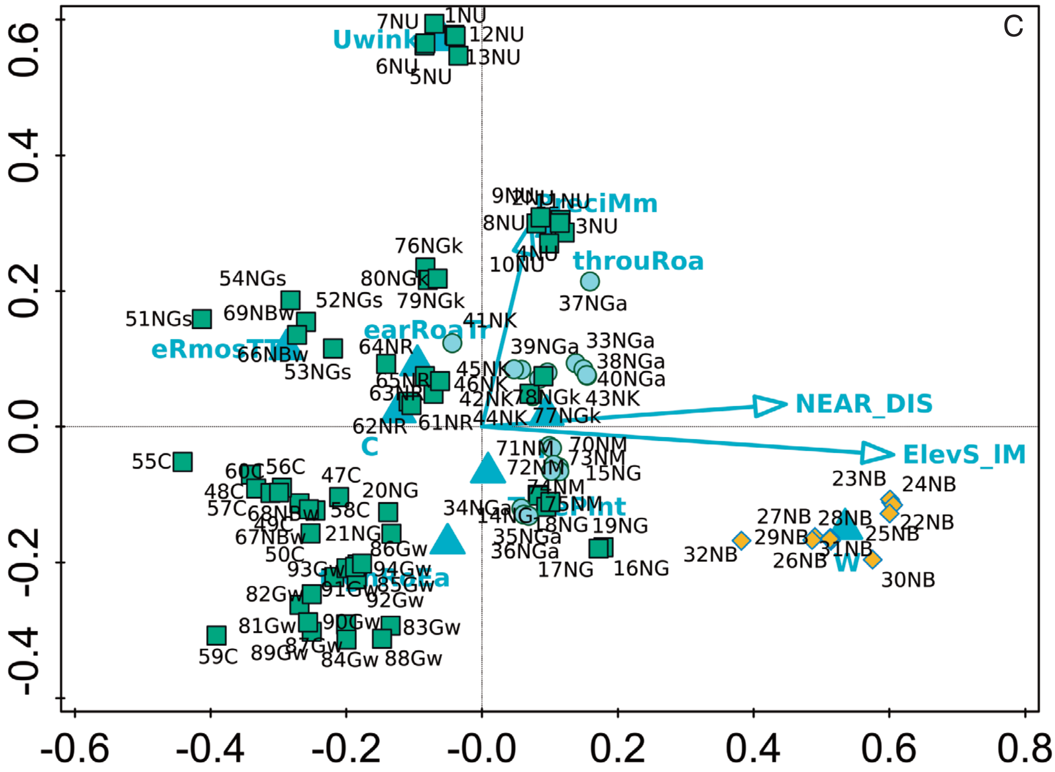


Figure 4.43 C: Biplot of axes two & three derived by tb-RDA. See text and above for more information.

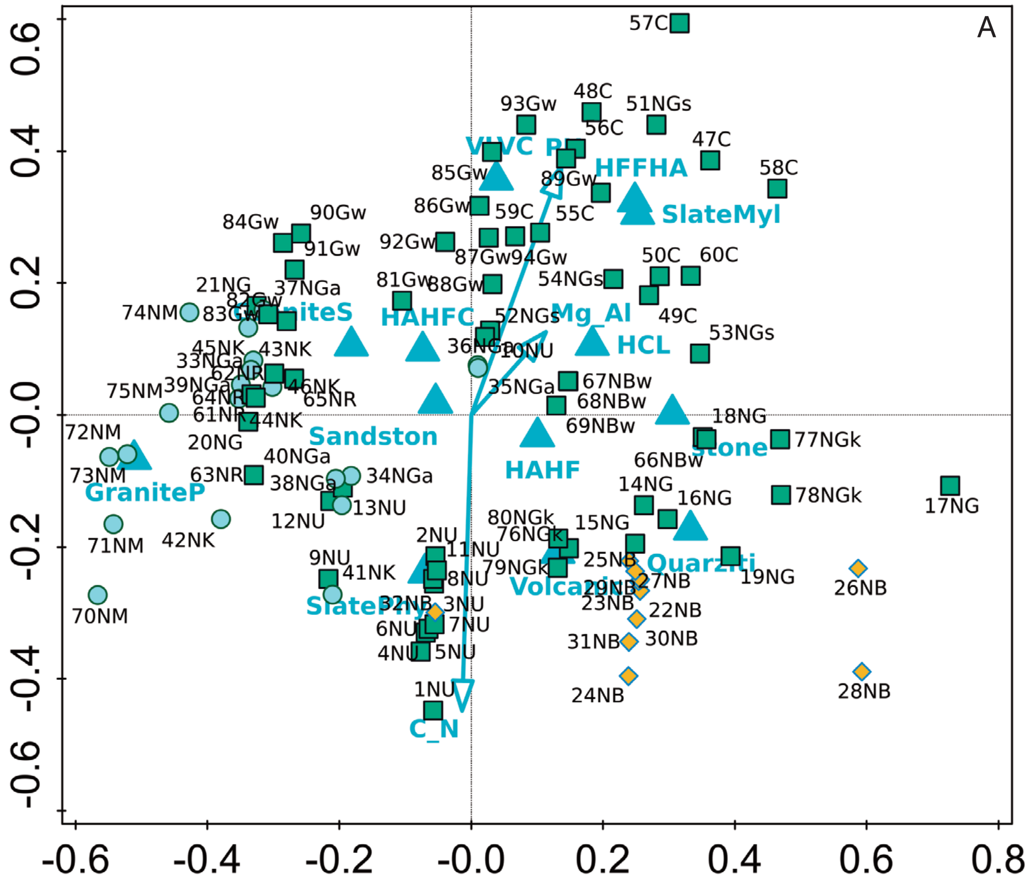


Figure 4.44 A to C: See next page for panes B & C. Biplot of axes one and two. Results of a tb-RDA with the soil factors as explanatory variables. More information can be retrieved from the text.

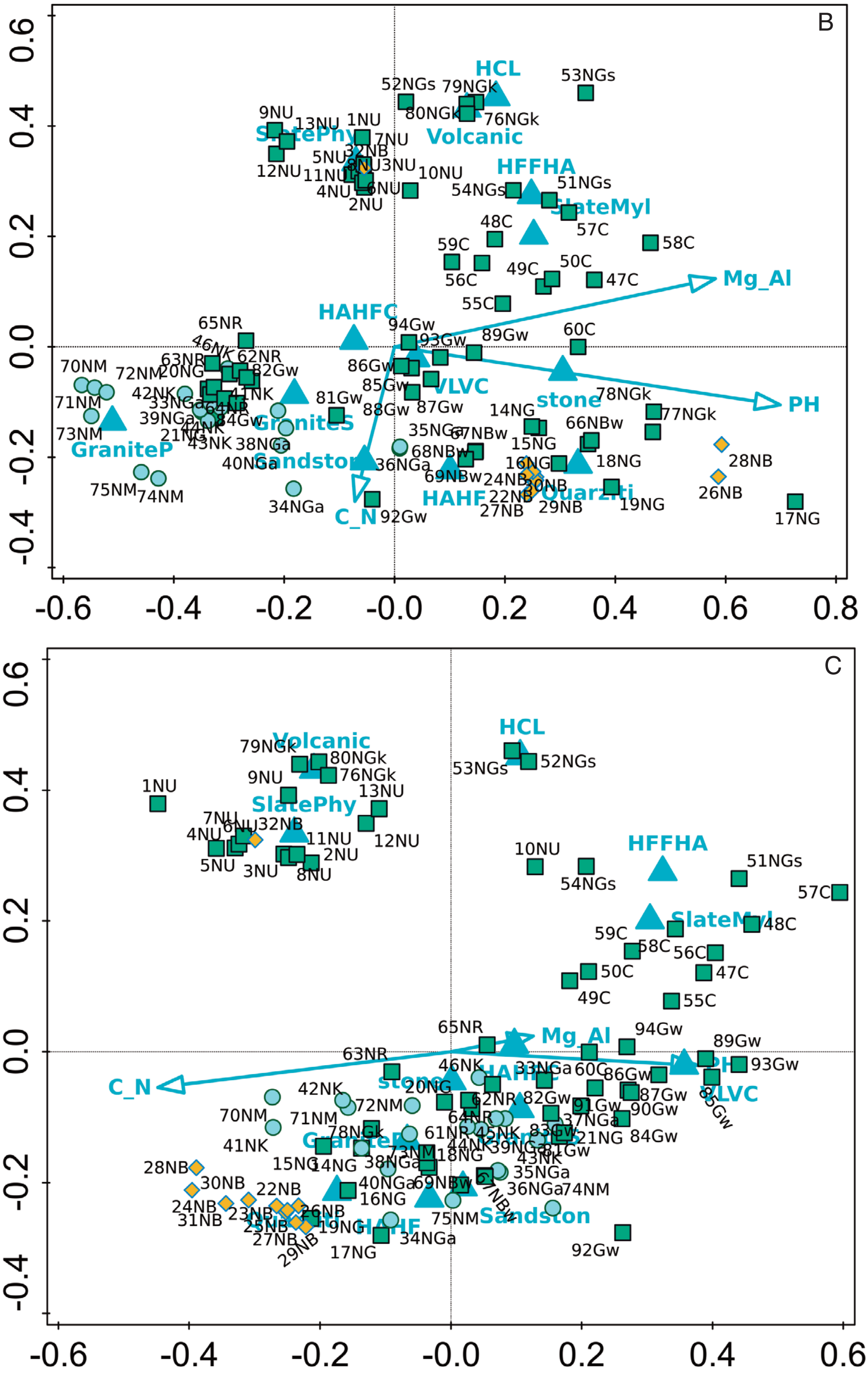


Figure 4.44 B and C: Biplots are derived by tb-RDA with the soil factors as explanatory variables. Pane B: axes one and three; Pane C axes two and three. Information on the interpretation can be retrieved from the text.

The partial approaches resulted in an explained variation of 15.39% (7.92%$_{adj}$) for the sole impact of the environmental variables. For the effects of the soil variables after the environmental effect had been partialled out, 27.50% (13.24%$_{adj}$) explained variation remained. Regarding the environmental variables, most of the matrix states lost statistical significance, as did the distance to the forest edge. While the number of soil parameters was also reduced, mostly by geological categories, [Al] itself gained explanatory power (Tabs. 4.19 and 4.20).

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.03	0.02	0.01	0.01	0.01
Explained variation (cumulative)	4.34	7.67	10.06	12.21	13.92
Pseudo-canonical correlation	0.82	0.83	0.77	0.78	0.77
Explained fitted variation (cumulative)	28.21	49.81	65.39	79.32	90.44

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
Elev_a_ s_l m	2.8	5	2.1	0.002	0.012
Precip_a mm	2.6	4.7	2	0.001	0.009
Matrix.Uwinka	3.6	6.4	2.8	0.001	0.018
Matrix.natintEg	2.3	4.1	1.8	0.003	0.0216
Congo_Nile.C	2.2	3.9	1.7	0.001	0.012
Matrix.TreePlnt	2	3.5	1.6	0.008	0.048

Table 4.19 a, b: Results of a partial tb-RDA with interactive forward selection based on the environmental parameters as explanatory variables. The impact of the soil factors has been removed prior to analysis. The lower table contains the environmental parameters left after interactive stepwise forward selection. Partial variation is 47.53702, explanatory variables account for 15.39% or 7.92%$_{adj}$. For VIFs see Annex 15 A.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.03	0.02	0.02	0.02	0.01
Explained variation (cumulative)	5.03	8.68	11.70	14.31	16.78
Pseudo-canonical correlation	0.81	0.85	0.87	0.77	0.80
Explained fitted variation (cumulative)	18.28	31.57	42.54	52.02	61.01

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
[C]:[N]	3.2	4.6	2.4	0.001	0.0094
[Al]	2.8	4	2.1	0.001	0.0094
pH	2.2	3.1	1.7	0.003	0.0235
Cat_Geol.SlateMylo	2.6	3.7	2	0.001	0.01567
Soiltype_FAO.HAHF	2.2	3.2	1.7	0.003	0.0235
Cat_Geol.Quarzitic	2.2	3.1	1.7	0.003	0.0235
Cat_Geol.GraniteSedi	2.1	3.1	1.7	0.008	0.0423
Soiltype_FAO.HAHFC	2	2.9	1.6	0.007	0.04113
Cat_Geol.Sandstone	2	2.9	1.7	0.009	0.03525
Limitation.stone	2	2.9	1.7	0.004	0.02686
Cat_Geol.Volcanic	2	2.9	1.7	0.005	0.02611
[Mg]:[Al]	2	2.9	1.7	0.006	0.0282

Table 4.20 a, b: Results of a partial tb-RDA with interactive forward selection based on the soil parameters as explanatory variables. The impact of the environmental factors has been removed prior to analysis. The lower table contains the soil parameters left after interactive stepwise forward selection. Partial variation is 48.13572, explanatory variables account for 27.50% or 13.24%$_{adj}$. For VIFs see Annex 15 B.

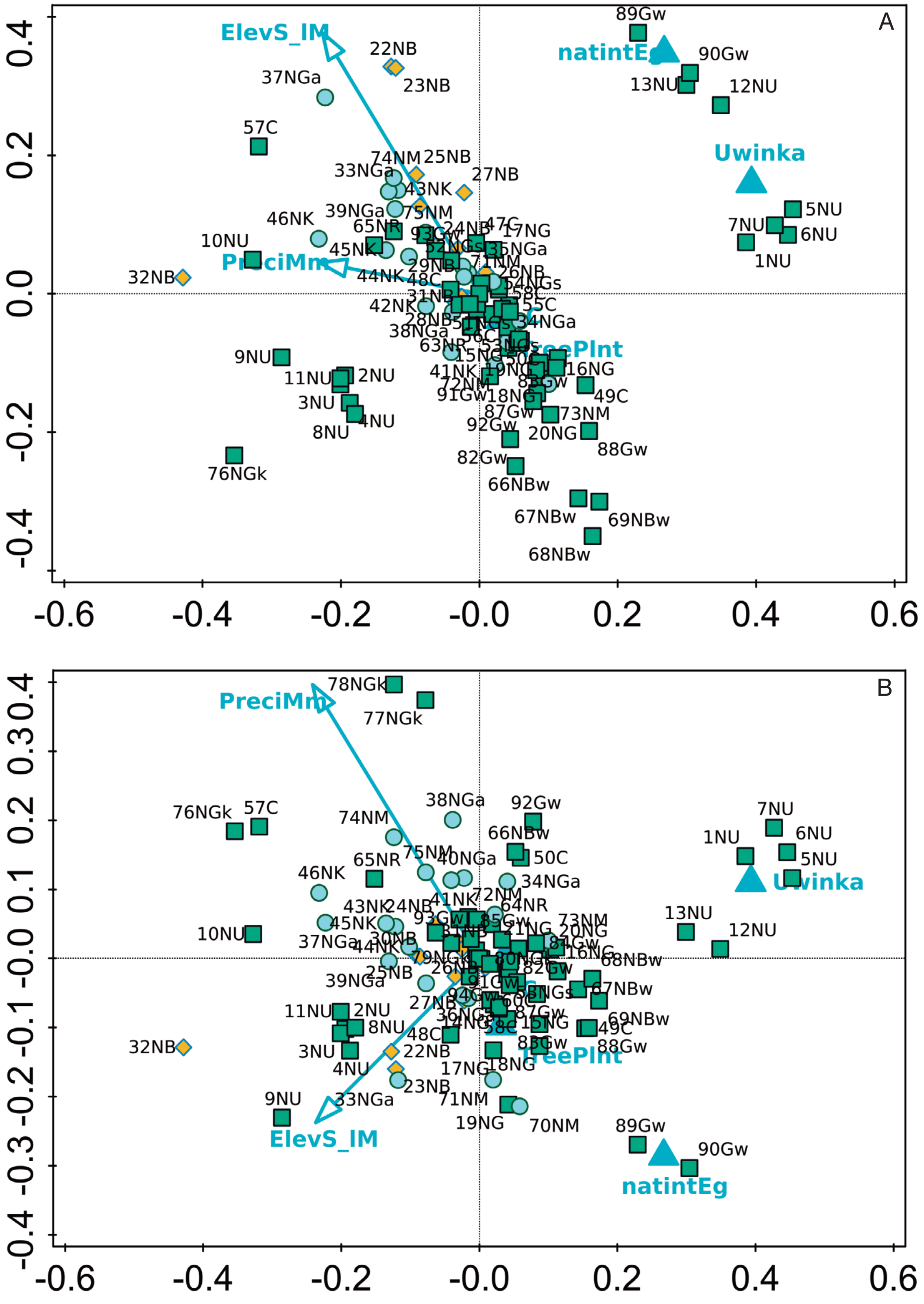


Figure 4.45 A and B: Biplots stemming from a partial tb-RDA with the environmental factors as explanatory variables. The effect of the soil parameters has been partialled out prior to analysis. Information on the interpretation can be retrieved from the text. Pane A shows a plot of axes one an two, Pane B of axes one and three.

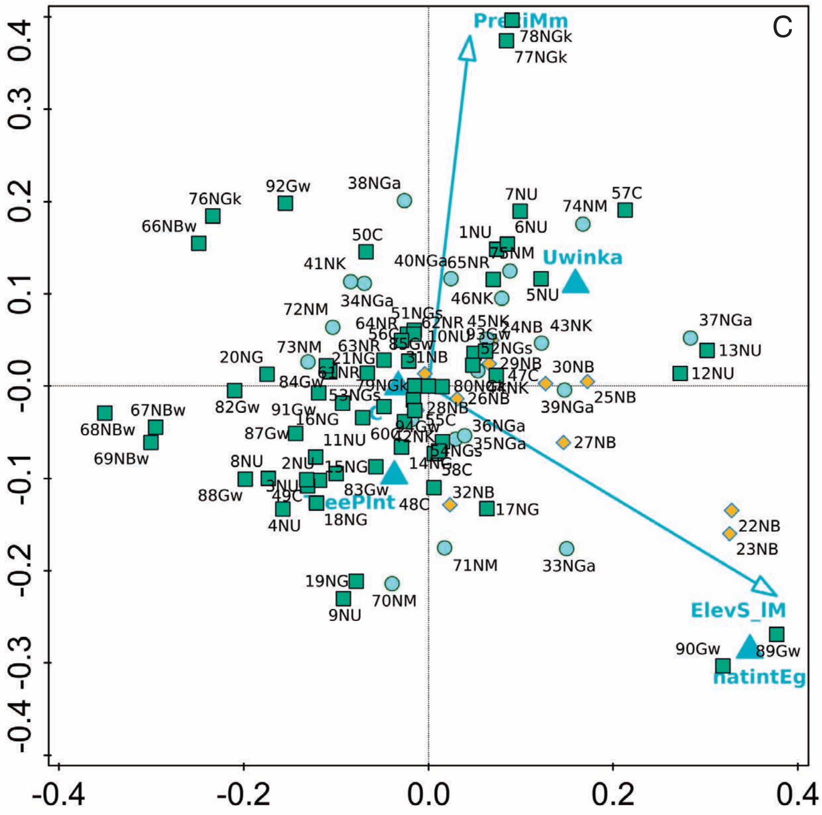


Figure 4.45 C: Biplot showing axes two and three stemming from a partial tb-RDA with the environmental factors as explanatory variables. The effect of the soil parameters has been partialled out prior to analysis.

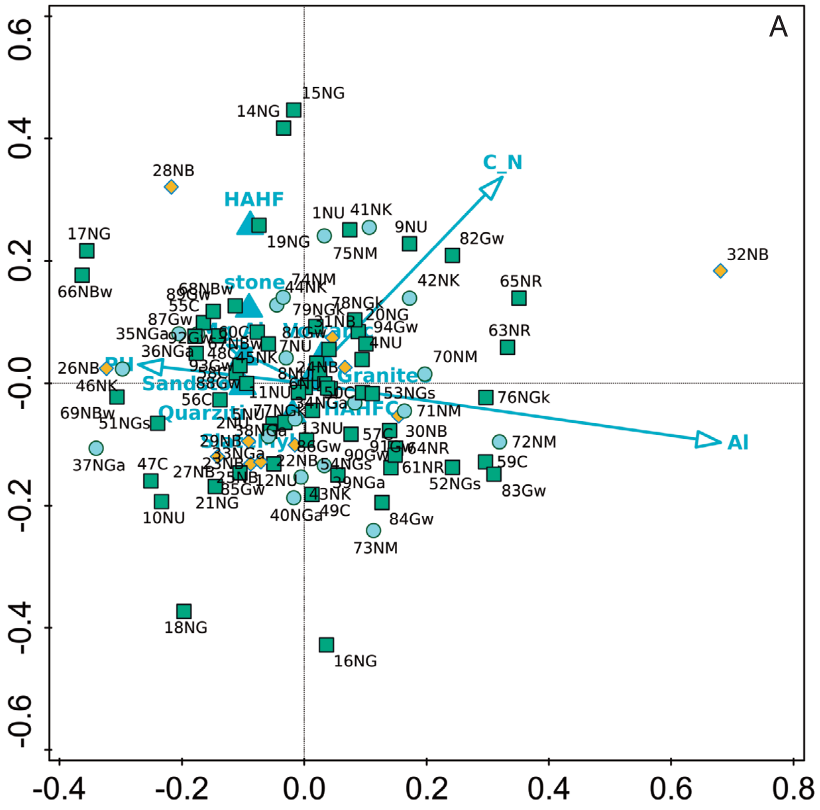


Figure 4.46 A: Biplot derived by a partial tb-RDA. See next page for captions.

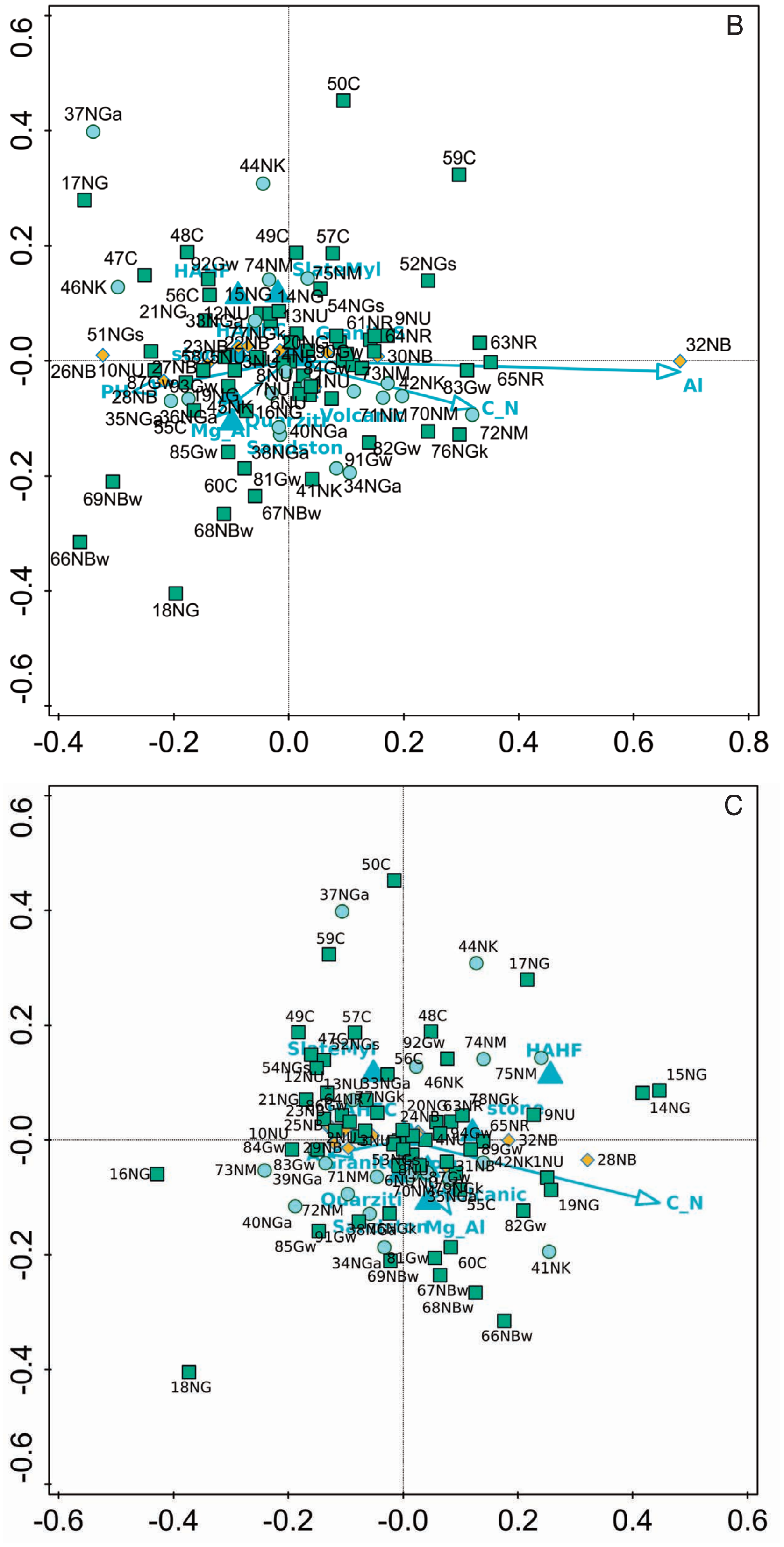
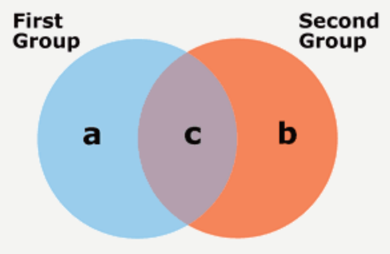


Figure 4.46 A to C: Biplots derived by a partial tb-RDA. The soil variables were used as explanatory variables after removing the effect of the environmental parameters. Shown are: In pane A the axes one and two, in pane B the axes one and three and in pane C the axes two and three. An interpretation is given in the text.

The variation explained by variation partitioning based on RDA using Hellinger transformation resulted in a corrected explained variation of a joined 35.00%. Of these, the environmental parameters account for 9.9%, the soil parameters for 11.90% and the joint impact sums up to 13.20%. Interpretation of the biplots has to progress with the same precautions as before. All of the variables are depicted in relation to all the other variables in the diagram in weighted distances from each other. Again, no new information could be gained concerning the general impact factors and the separation of the samples along the respective gradients. Alone, the resolution along the axes appears to be partly higher.

Fraction	Variation(adj)	% of Explained	% of All	DF	Mean Square
a	0.10	28.30	9.90	20.00	0.01
b	0.12	34.00	11.90	19.00	0.01
c	0.13	37.70	13.20	--	--
Total Explained	0.35	100.00	35.00	39.00	0.02
All Variation	1	--	100	93	--



Group Members: First Group	Second Group
Precip_a mm	Mg_Al
Elev_a_ s_l m	Soiltype_FAO
NEAR_DIST	Limitation
Matrix	C_N
Congo_Nile	pH
	Cat_Geol

Tested Fraction	F	P
a+b+c	2.3	0.001
a	1.6	0.001
b	1.7	0.001

Table 4.21 a - c: Results of a variation partitioning approach based on tb-RDA. The environmental parameters and the soil parameters recorded were employed to set up the groups. The upper table contains the explanatory power of the fractions. The table on the right displays the explanatory variables contained in the respective group. The table below the Venn diagram contains the statitistical significances after Monte Carlo permutation. The Venn diagramm is used to illustrate the groups and the fractions of explained and unexplained variation. Remember: Fraction c is not an interaction term. This common fractions represents the correlation of explanatory variables in the two sets. For VIFs see Annex 16.

From the plot of axes one and two, the usual separation of the samples along the elevational gradient can be taken (Fig. 4.47 A). In detail, the interpretation again presents some pitfalls. The samples from Mt Muzimu, for instance, have been placed below the ones from Mt Bigugu. In general, this representation is correct, but when it comes to sample 17_{NG}, one of the samples close to the summit of Mt Muzimu, the positioning in the graph is misleading. The same is true for the positioning towards the vector representing precipitation. Precipitation on site is right in the middle of the gradient. No solution as to the positioning of sample 17_{NG} can be found in the data measured. Neither the relatively high [C]:[N] ratio conflicting with a likewise increased pH value nor the forest matrix seem to offer a sufficient solution. The same holds true for sample 18_{NG}. Some explanatory value may come from the positioning of the geological factor level quartzitic; this is the geological basis on which not only the samples directly from the watershed could be found but also samples from Bweyeye and Gisakura. The limitation of the drillable soil depth by stone, which is not only found at higher altitudes, may also add to the placement of the Mt Muzimu samples in the graph. Given the further interplay and reciprocal dependencies of the respective response and explanatory variables (e.g., pH-values) involved, the ordination thus displays only the coarser relations. Which might be exacerbated by the small fractions of variation explained (ter Braak & Šmilauer, 2012, p. 228). Another group of samples positioned ambivalently are some samples from Gahurizo and Kitabi. Although they are near the far end of the elevation scale, the samples are to be found at altitudes below the ones from Mt Muzimu. A similar observation can be made for precipitation. As they are at the lower end of the scale, the samples nevertheless receive more rainfall than the samples from Gishwati Forest.

Before concluding this section, we will find out if and where the samples found to "cross" the watershed and/or forest borders have been positioned by the direct ordination methods. Polar Ordination, as well as PCoA, brought to light that at least along axis one several samples from Gishwati Forest, Ruzizi, Uwinka and Gisovu have been placed quite far from the bulk of the samples from the same location. For sample 32_{NB}, the altitude and geology seem to provide the only meaningful information. The positioning along the vector representing precipitation gives a distorted picture. Although 32_{NB} has the lowest precipitation of all the Mt Bigugu samples, the separation in the plot is large compared to the real values. What is true for variation partitioning based on RDA is less pronounced in the CCA based version. In the plot of axis one against axis two, interpretation is hampered by the tight placement of the samples. Here, places between Mt Muzimu and Mt Bigugu have been changed along the elevational gradient putting the Samples from Mt. Bigugu closer together. Sample 9_{NU}, placed further apart from sample 11_{NU} by CCA, is still positioned among the samples from the Nile side of the watershed. Although the [C]:[N] ratio at the sample site is among the highest, it does not suffice to set the sample apart from all of the samples from Uwinka, which did not occur in the cases of samples 1_{NU} and 4_{NU}; however, the relations still do not correspond to the measured values, with sample 1_{NU} showing the largest [C]:[N] ratio in total. Another impact is the soil type. The humic acrisols / humic (ferralic) cambisols are widespread throughout the survey. Most of the samples with this soil type show lower [C]:[N] ratios and elevated pH values. Hence, the positioning of sample 9_{NU} results partly from its combination of soil type, [C]:[N] ratio and pH values. The same is valid for a part of the samples from Gishwati Forest, all of which have lower than average [C]:[N] ratios as well as increased pH values situated on the same soil type. Sample 9_{NU} is set apart by a lower pH value. Though not as much, the samples from Ruzizi are still positioned amongst the samples from the Nile side of the watershed by CCA. Except for sample 62_{NR}, which has been positioned further apart respectively, all samples from Ruzizi show low [Mg]:[Al] and [Ca]:[Al] ratios. On average, pH levels are lower for the Ruzizi samples than for Gishwati Forest, resulting in the Ruzizi samples being placed between sample 9_{NU} and most of the Gishwati samples. Though Ruzizi receives more precipitation than Gishwati Forest, and the samples are placed accordingly in the graph, overall relations are not well depicted by CCA. The plot showing the second and third axes displays the relations better though still with considerable difficulties in interpretation (Fig. 4.47 C).

The graphs received by variation partitioning based on tb-RDA have to be interpreted with equal care but give a clearer picture. Here, as well, the overall gradients are depicted reasonably well. Single relations between impact factors and samples have to be elucidated by consulting the actual values of the explanatory variables.

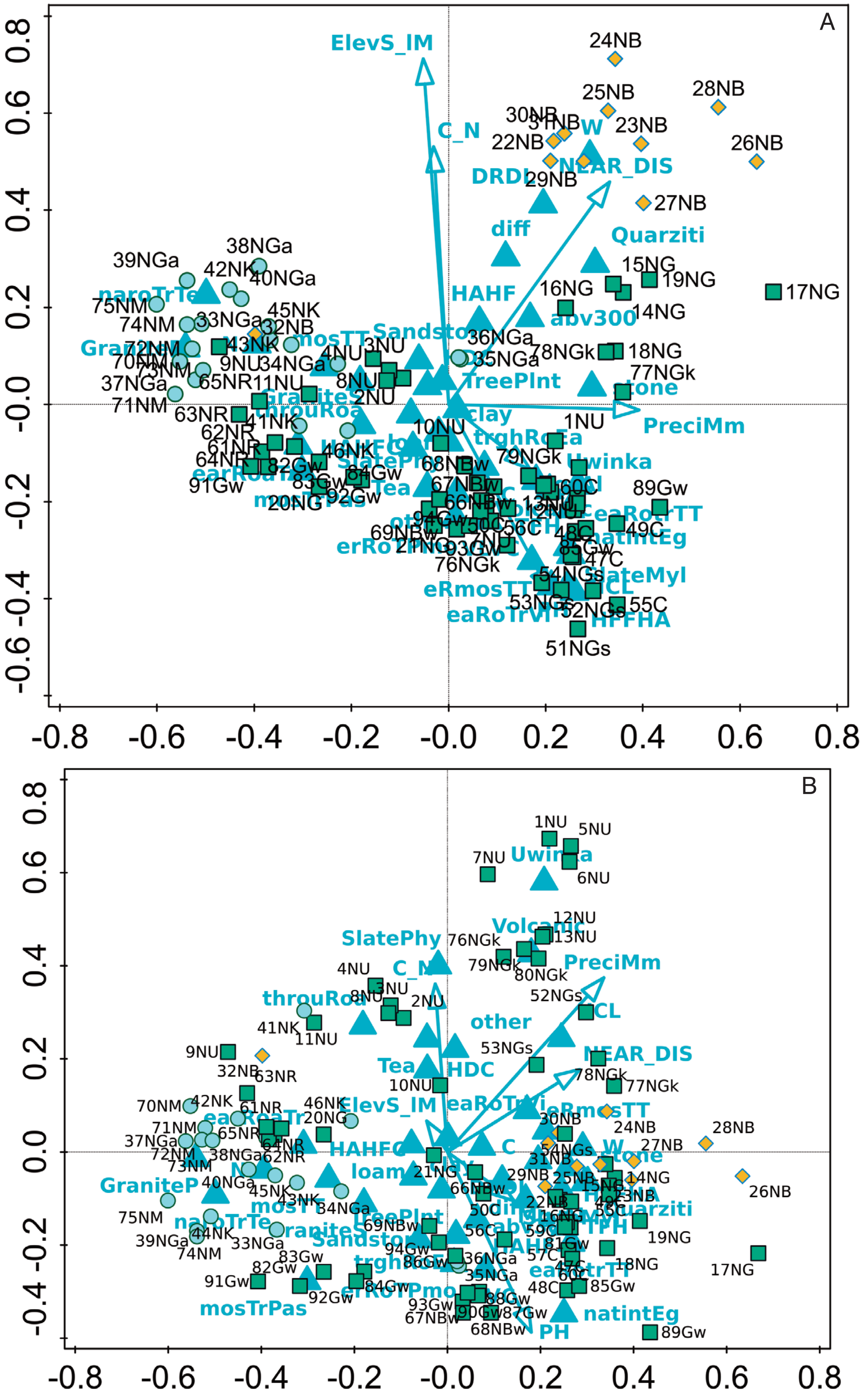


Figure 4.47 A and B: Biplots derived by variation partitioning based on tb-RDA. The two groups of explanatory variables are composed of the environmental and soil variables, respectively.

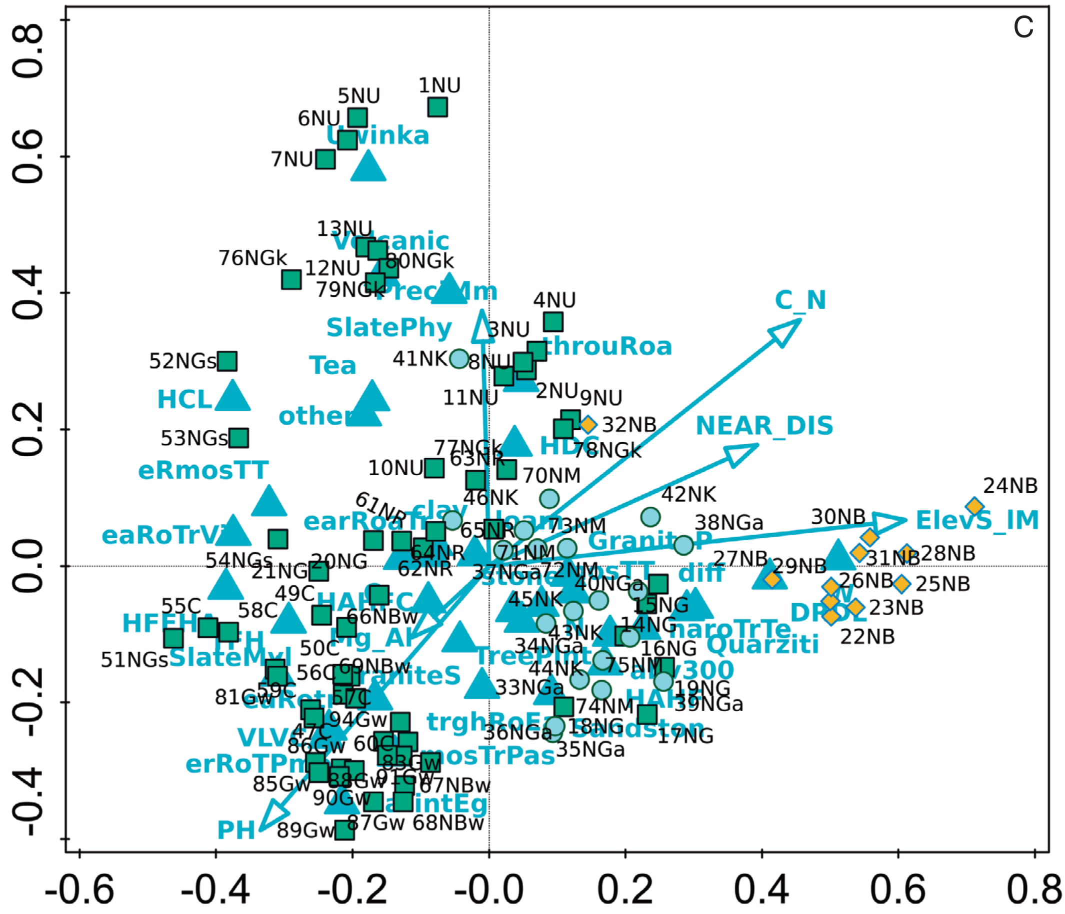


Figure 4.47 A to C: The biplots are stemming from variation partitioning based on tb-RDA. The conditional effects of the environmental and soil factors as explanatory variables were evaluated. Shown are: In pane A the axes one and two, in pane B the axes one and three and in pane C the axes two and three. An interpretation is given in the text.

4.2.5 The Spatial Component

Now that the environmental impact has been determined within the framework of the data at hand, the question concerning its spatial extent, or more precisely, its spatial structure has to be answered. It is well known that environmental phenomena can be spatially structured, e.g., the precipitation in our data decreasing from west to east. There are also other phenomena that might be spatially structured, such as dispersion, competition and other biotic processes (LEGENDRE & LEGENDRE, 2012). Using a simple CCA and a simple DCA, a systematic change in species scores along the axes (only four axes are shown Figs. 4.48 & 4.49) can be found. The pattern of the case scores can be outlined in the geographical XY coordinate space. The linear models based on PCA and RDA, respectively, explained even more of the variation in species composition while finding the same overall trend (Fig. 4.50). In both approaches, the previously identified impact factors were used as independent variables. The case scores resulting from both the unconstrained and constrained analyses were then used to outline their relationship to the X and Y coordinates using a loess smoother model. The case scores resulting from the constrained analyses provide the best gradients in community composition that can be elucidated utilising the independent variables recorded. Therefore, an indication of the spatial variation in the environmentally determined community variation can be obtained. At the same time, a comparison can be undertaken with the spatial patterns obtained through unconstrained analyses. See ŠMILAUER & LEPŠ (2014) for further information.

	1	2	3	4
Explained by constrained axis [%]	10.51	6.80	5.95	4.28
Explained by unconstrained axis [%]	12.20	7.40	7.29	5.35
Efficiency of constrained axis [%]	86.2	91.84	81.65	80.01

	Axis 1	Axis 2	Axis 3	Axis 4
Axis 1	-0.92	-0.02	0.01	0.00
Axis 2	0.01	-0.42	0.86	0.04
Axis 3	-0.01	0.78	0.37	0.22
Axis 4	0.00	-0.12	-0.09	0.85

Table 4.22 a, b: Comparison of a RDA and a PCA. An explanation is given in the captions for table 4.23 below.

	1	2	3	4
Explained by constrained axis [%]	3.74	3.40	3.31	3.05
Explained by unconstrained axis [%]	4.00	3.56	2.81	2.33
Efficiency of constrained axis [%]	93.32	95.45	117.79	131.01

	Axis 1	Axis 2	Axis 3	Axis 4
Axis 1	0.91	-0.29	0.03	-0.12
Axis 2	-0.02	0.07	-0.12	-0.09
Axis 3	0.00	0.28	-0.04	-0.01
Axis 4	-0.07	0.30	-0.29	-0.01

Table 4.23 a, b: Comparison of a CCA and a DCA. The efficiency of the constrained axes is calculated as the percentage of variation explained by a constrained axis devided by the percentage explained by the corresponding unconstrained axis, mulitplied by 100. A low efficiency indicates that the available independent varibales are not able to explain the dominant pattern in the response data. The lower table containes the cross-correlations of the constrained (in rows) and unconstrained (columns) axes. If the corresponding axes of the two ordinations would depict the same part of the variation, the values on the diagonal would be the highest absolute values.

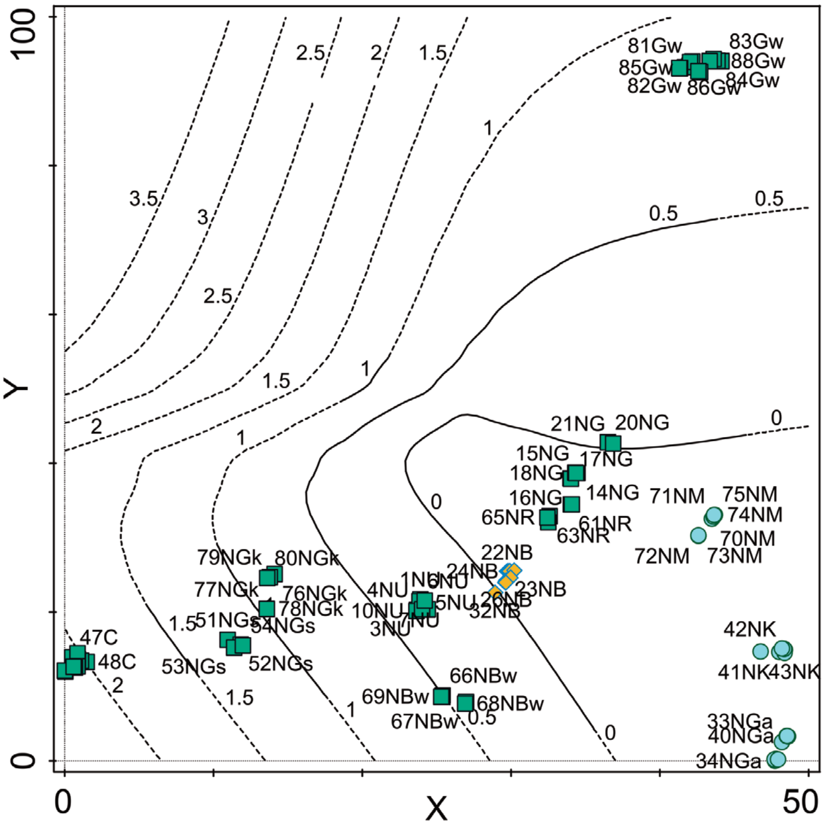


Figure 4.48: Contour plot depicting the smoothed changes of the sample scores along axis one projected onto the geographic space. In this way an indication can be attained as to the spatial variation in the environmentally determined variation in community composition. Here the the scores along the first axis resulting from a CCA are shown. The first axis accounts for 4% of the variation explained by the independent variables.

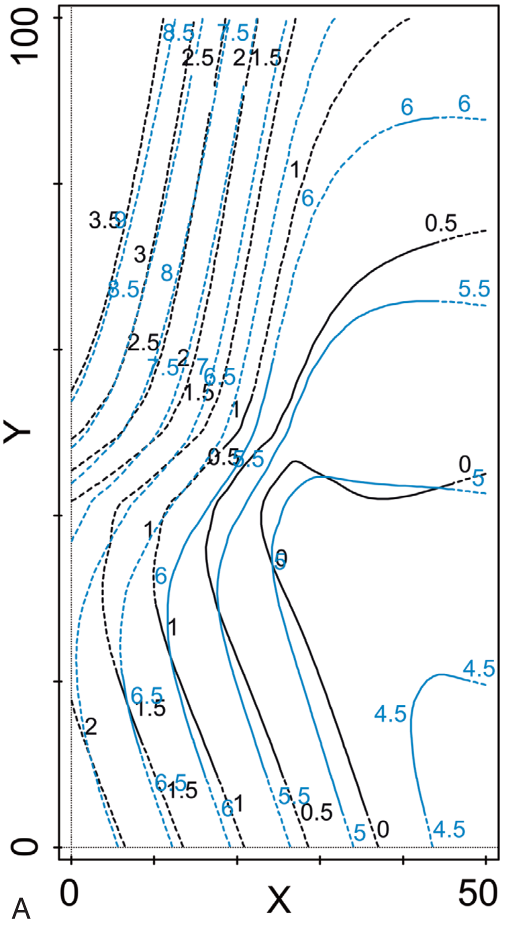


Figure 4.49 A to D: Contour plots depicting the smoothed changes of the sample scores along the axes projected onto the geographic space. The sample scores were derived from a CCA and a DCA, respectively. The light blue lines illustrate the sample scores from the unconstrained analysis and the black lines the sample scores from the constrained analysis. The low cross-correlation among the unconstrained and constrained axes, as already revealed in Table 4.23, is readily visible in panes B to D of the figure. The plot of the first axis in pane A shows a systematic change in the scores of the samples in both CCA and DCA along this axis. Systematic changes are also visible for the consecutive three axes (B to D), although the corresponding axes of the two ordinations depict different parts of the variation. See also Table 4.23 b for comparison. It can also be seen from the plots that the fraction of variation explained decreases with the order of the axis in each case. Resulting from CCA axis two (pane B) represents 3.56% of the variation explained by the environmental factors s.l. Axis 3 (pane C) describes 2.81% and axis four (pane D) shows 2.33%. The variation explained by each axis can also be taken from Table 4.23 a.

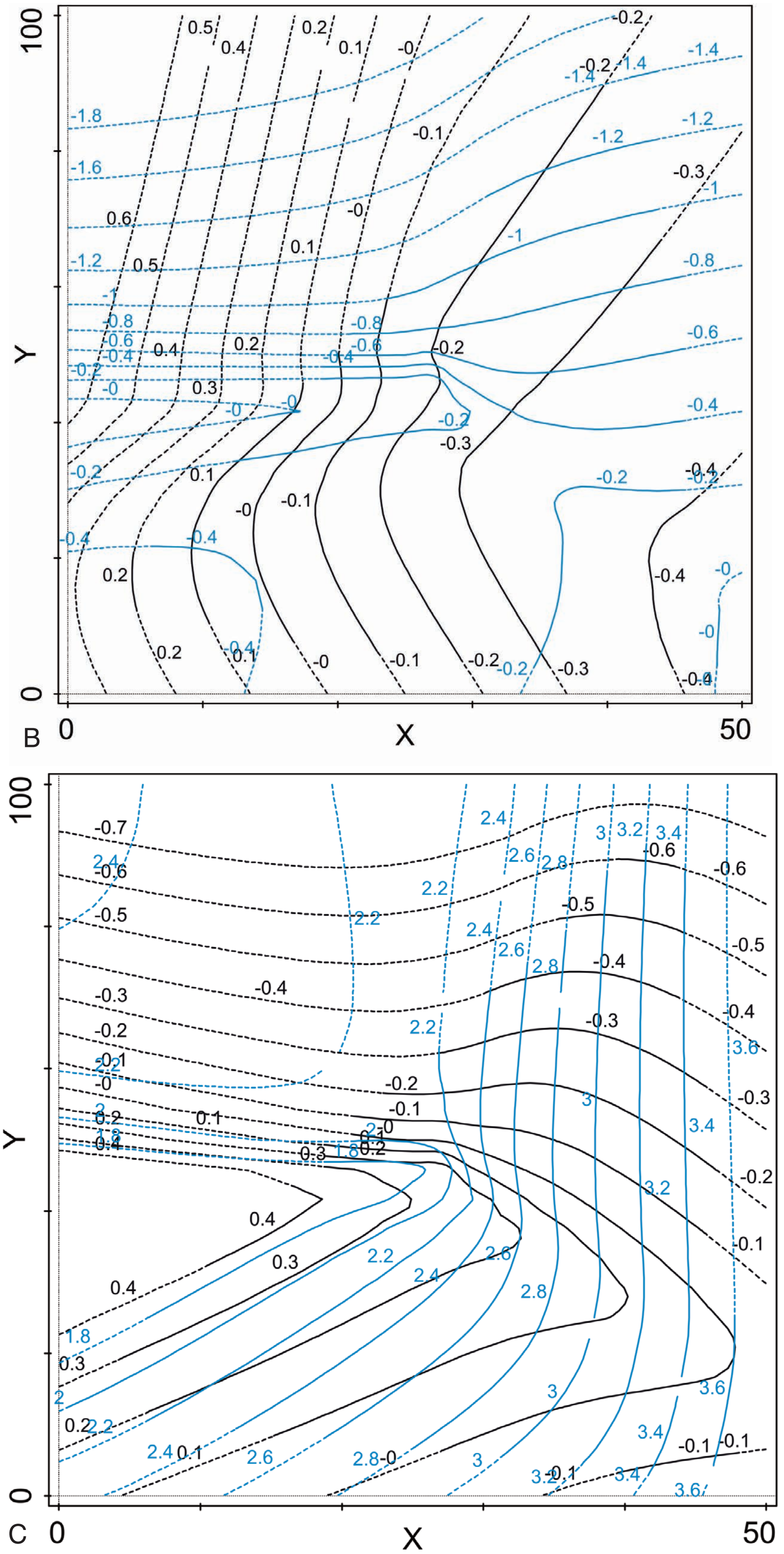


Figure 4.49 B, C: Contour plots showing the smoothed changes of the sample scores along the second (B) and third (C) axis. See captions of pane A for interpretation.

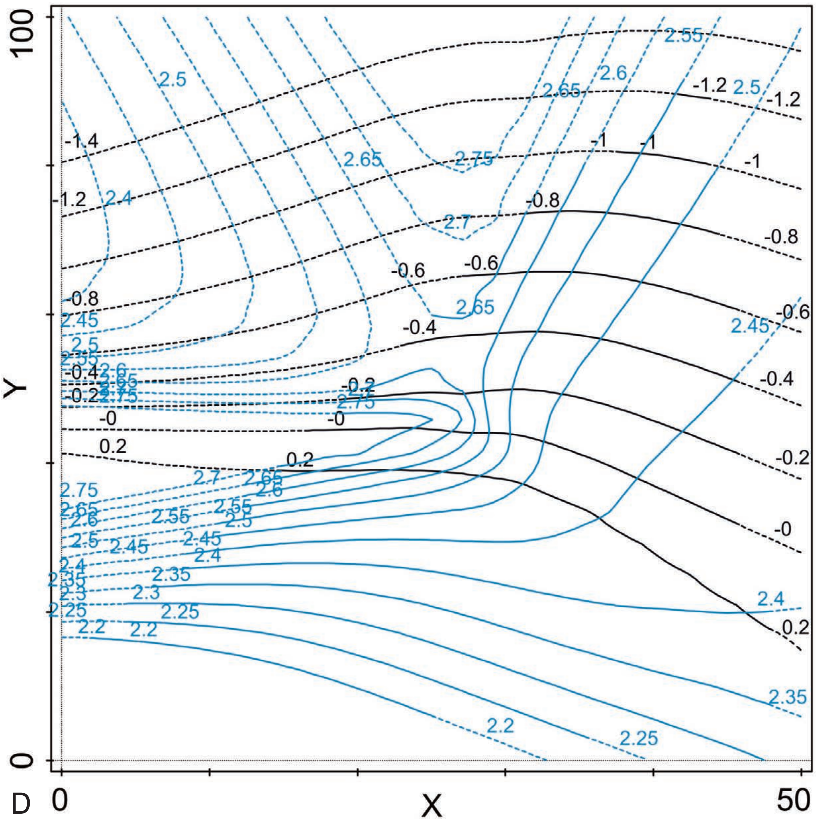


Figure 4.49 D: Contour plot depicting the smoothed changes of the sample scores along the fourth axis (based on CCA & DCA). See pane A for interpretation.

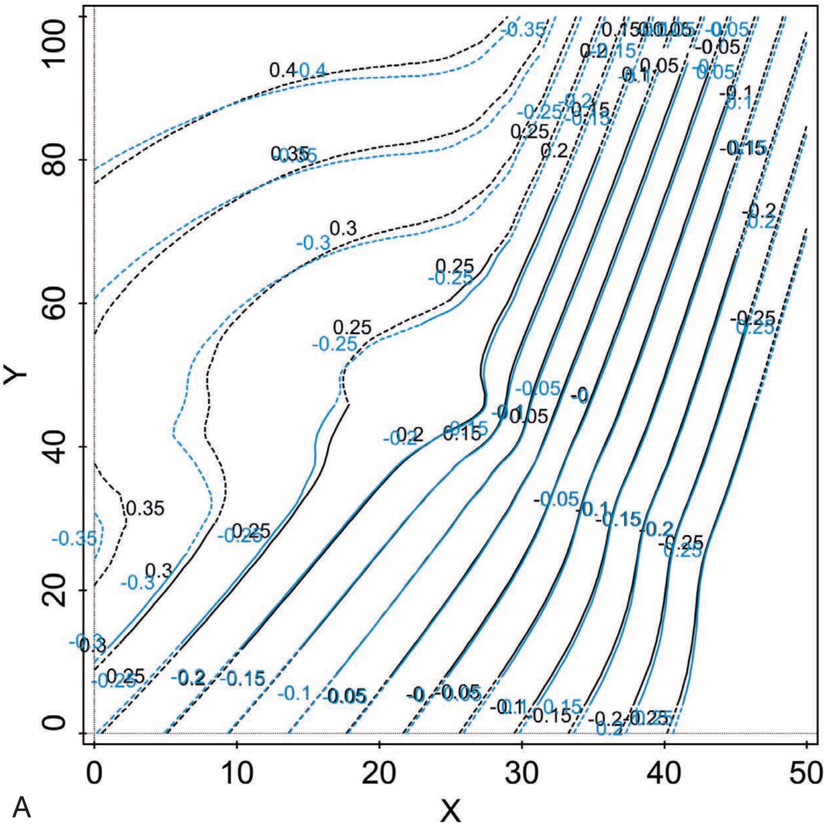


Figure 4.50 A: PCA & RDA derived contour plot. For interpretation see page 299.

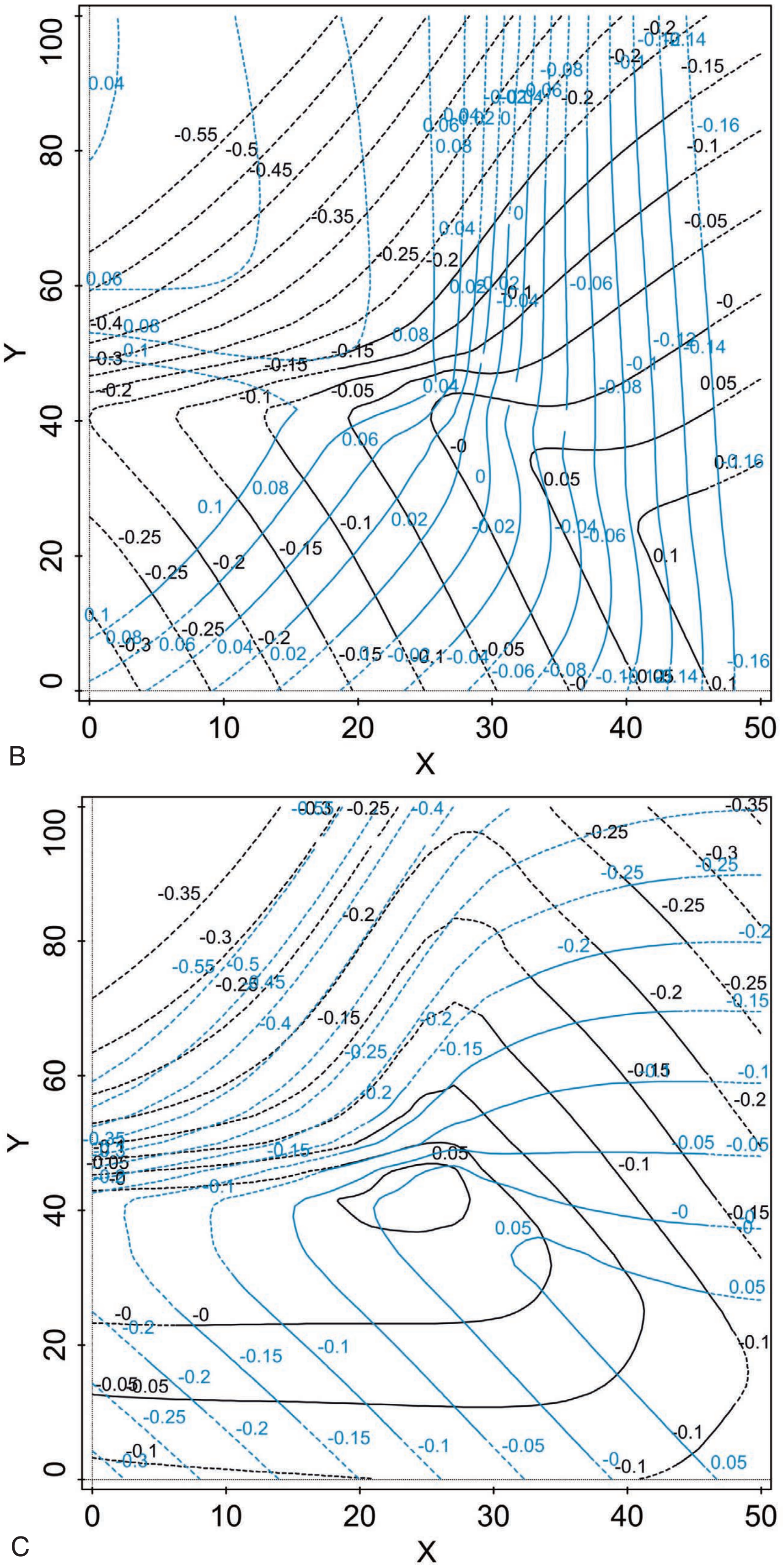


Figure 4.50 A: PCA & RDA derived contour plots of axis two (B) and axis three (C). For interpretation see page 299.

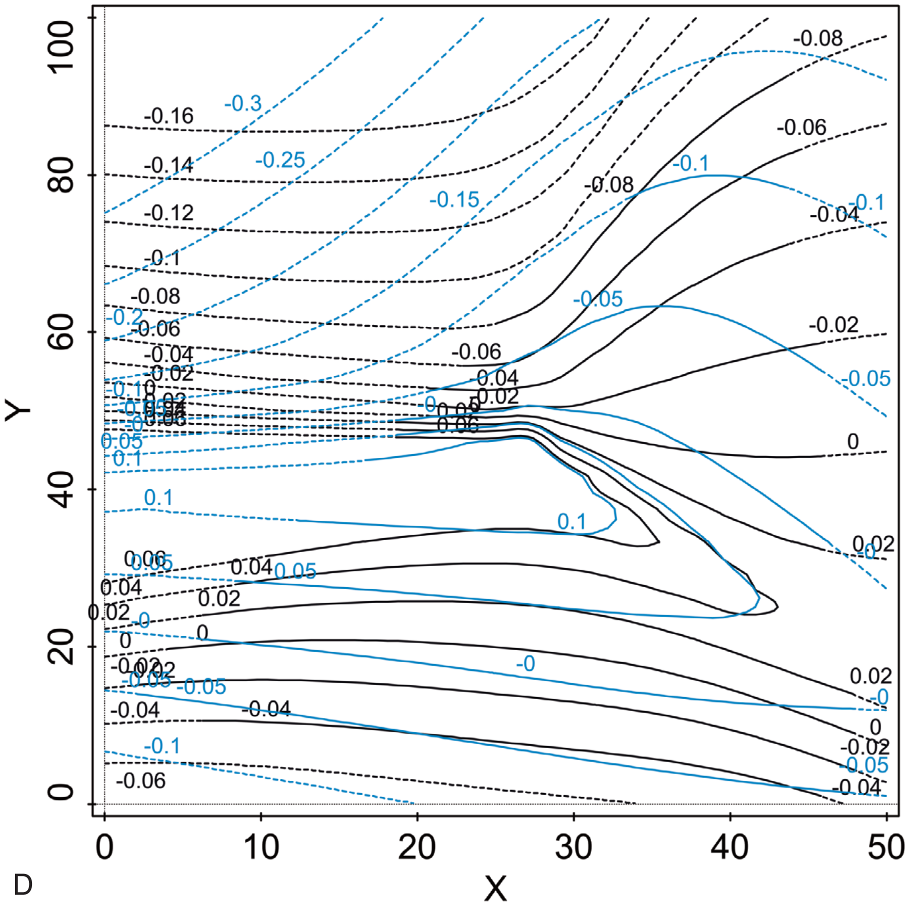


Figure 4.50 A to D: Contour plots depicting the smoothed changes in the sample scores along the axes projected onto the geographic space. The sample scores were derived from a PCA and a RDA, respectively. The light blue lines illustrate the sample scores from the unconstrained analysis and the black lines the sample scores from the constrained analysis. As already revealed in Table 4.22 b, the correlation between the first axes of PCA and RDA is quite high, although it is negative. The resulting graph, 4.50 A, depicts an according systematic change of sample scores along axis one in both PCA and RDA. Negative as well is the moderate cross-correlation between both analysis for axis two. The same is true for axis three, albeit the correlation is positive. For axis four (pane D), the correlation is quite high, which is reflected in the isolines of the graph. The percentage of variation explained per axis can be seen in Table 4.22 a.

4.2.5.1 Trend Surface Analysis

A further broad-scale and coarse approach was used to find the major direction of the global spatial trend in the data. However, the trend surface analysis (Legendre & Legendre, 2012) conducted did not help much in reducing the data. Of the nine polynomial terms, eight were chosen during the interactive stepwise forward selection procedure. For both the linear and the unimodal approach, the X coordinates revealed the strongest relation to community composition followed closely by the Y coordinates. As Šmilauer & Lepš (2014) stated, these trends are far-reaching and take the form of monotonous or smooth non-linear changes. Hence, including all scales and directions for the unimodal framework, global spatial trends account for an adjusted 7.55% of the variation while, in the linear framework, $16.01\%_{adj}$ of the variation in species data are founded in spatial variation (Tables 4.24, 4.25). At this point, a reminder seems appropriate. To keep the models comparable and to eliminate the impact of outliers, three samples have been removed from the CCA-based approach. The amount of explained variation is reduced by about three percent by keeping samples 10_{NU}, 57_C and 60_C in the analysis. Thus, a comparison between the linear and unimodal approach should be drawn with care. As with the analyses before, a biplot is not the best option to interpret the results. In general, only two directions are represented by the included coordinates and their polynomial terms, so the arrows of the individual terms in a biplot cannot be used to truly infere the actual change in species composition in space. Therefore, in the following, the same procedure was chosen as in the determination of the global trend. The constrained case scores calculated by trend surface analysis using the spatial coordinates and their polynomials are plotted in XY space to reveal possible patterns in the case scores.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.67	0.57	0.43	0.39	0.35
Explained variation (cumulative)	3.40	6.31	8.47	10.43	12.21
Pseudo-canonical correlation	0.95	0.91	0.88	0.85	0.81
Explained fitted variation (cumulative)	21.56	40.01	53.72	66.13	77.41

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
Xc*Xc*Xc	3.1	19.5	2.8	0.001	0.001
Yc*Yc	2.8	17.6	2.6	0.001	0.00114
Xc	2.1	13.3	2	0.001	0.00267
Xc*Xc	1.6	9.8	1.5	0.002	0.004
Xc*Yc*Yc	1.4	8.8	1.3	0.029	0.03867
Yc	1.4	8.7	1.3	0.029	0.03867
Yc*Xc*Xc	1.7	11	1.7	0.001	0.002
Yc*Yc*Yc	1.8	11.2	1.7	0.001	0.0016

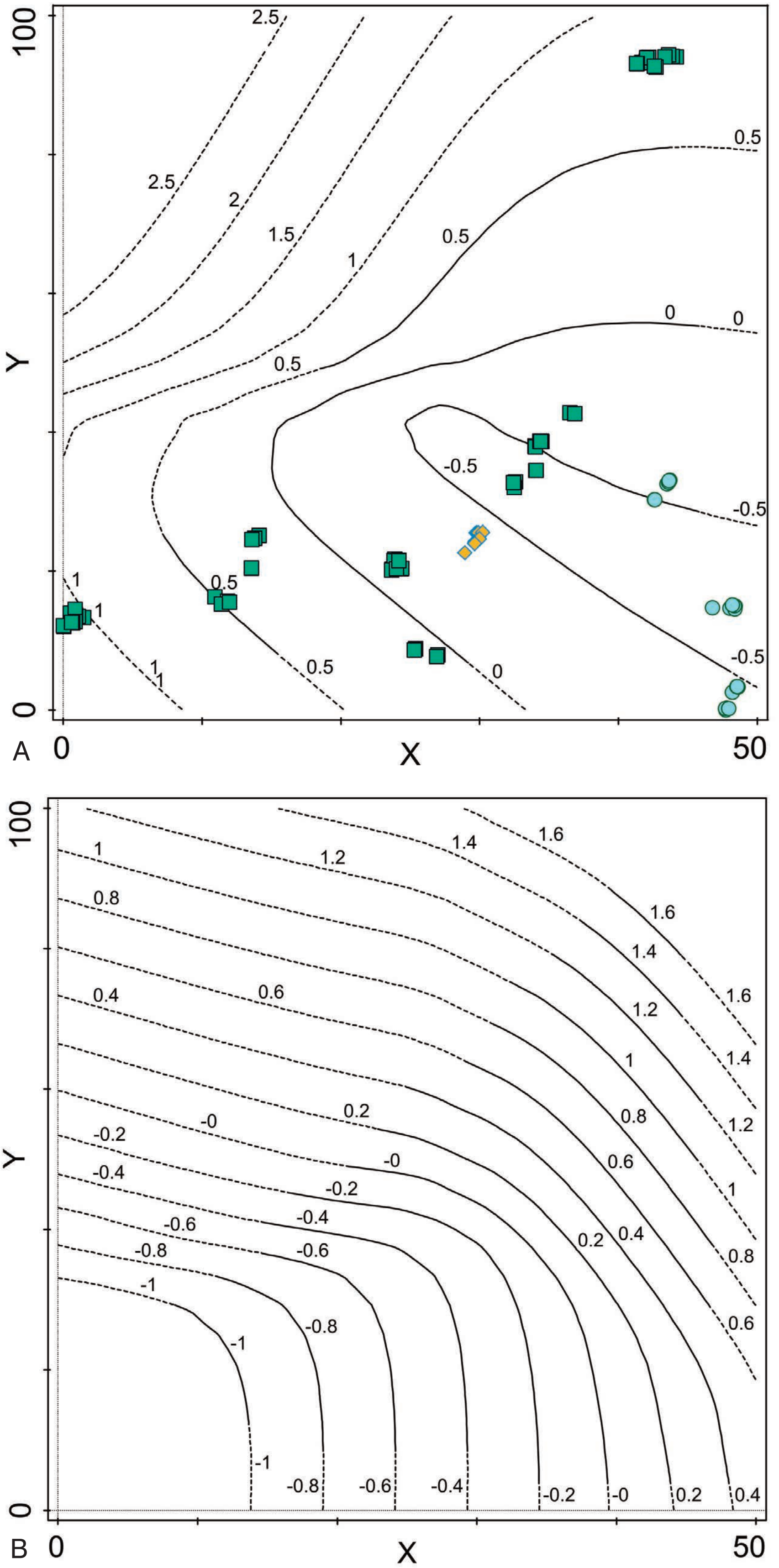
Table 4.24 a, b: Result of a trend surface analysis using the centred geographical coordinates as explanatory variables. The total variation for the unimodal approach is 19.73500. The explanatory varibales accounted for 15.77% or $7.55\%_{adj}$ of the variation in the species data. The lower table contains the geographical directions and surfaces showing a correlation to the pattern in species distribution.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.07	0.06	0.03	0.02	0.02
Explained variation (cumulative)	6.56	12.19	14.94	17.26	19.38
Pseudo-canonical correlation	0.82	0.87	0.78	0.69	0.82
Explained fitted variation (cumulative)	28.23	52.45	64.30	74.27	83.41

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
Xc	5.5	22.5	5.4	0.001	0.001
Yc*Yc	4.6	19	4.7	0.001	0.001
Xc*Xc*Xc	3.4	13.8	3.5	0.001	0.0015
Xc*Xc	2	8.2	2.1	0.003	0.00675
Yc	1.6	6.5	1.7	0.01	0.01286
Yc*Xc*Xc	2.1	8.7	2.3	0.002	0.0036
Yc*Yc*Yc	2.2	9	2.4	0.001	0.00225
Xc*Yc*Yc	1.8	7.4	2	0.003	0.00386

Table 4.25 a, b: Result of a trend surface analysis using the centred geographical coordinates as explanatory variables. The total variation for the tb-RDA approach is 79.70868. The explanatory varibales accounted for 23.23% or $16.01\%_{adj}$ of the variation in the species data. The lower table contains the geographical directions and surfaces showing a correlation to the pattern in species distribution.

Figure 4.51 A to D: Contour plots depicting the smoothed changes in the sample scores along the ordination axes projected onto the geographic space. The centred X and Y coordinates as well as their polynomials up to the third order were used as explanatory variables in a CCA. The axes are shown in increasing order beginning with axis one in pane A and ending with the fourth axis in pane D. Pane A contains the colour-coded samples plots for orientation. For pane A a change in the sample scores along the first axis can be seen that corresponds to a change in E-W direction, i.e., along the X axis. The figures are shown on pp. 305-306. The amount of variation explained can be taken from table 4.24.



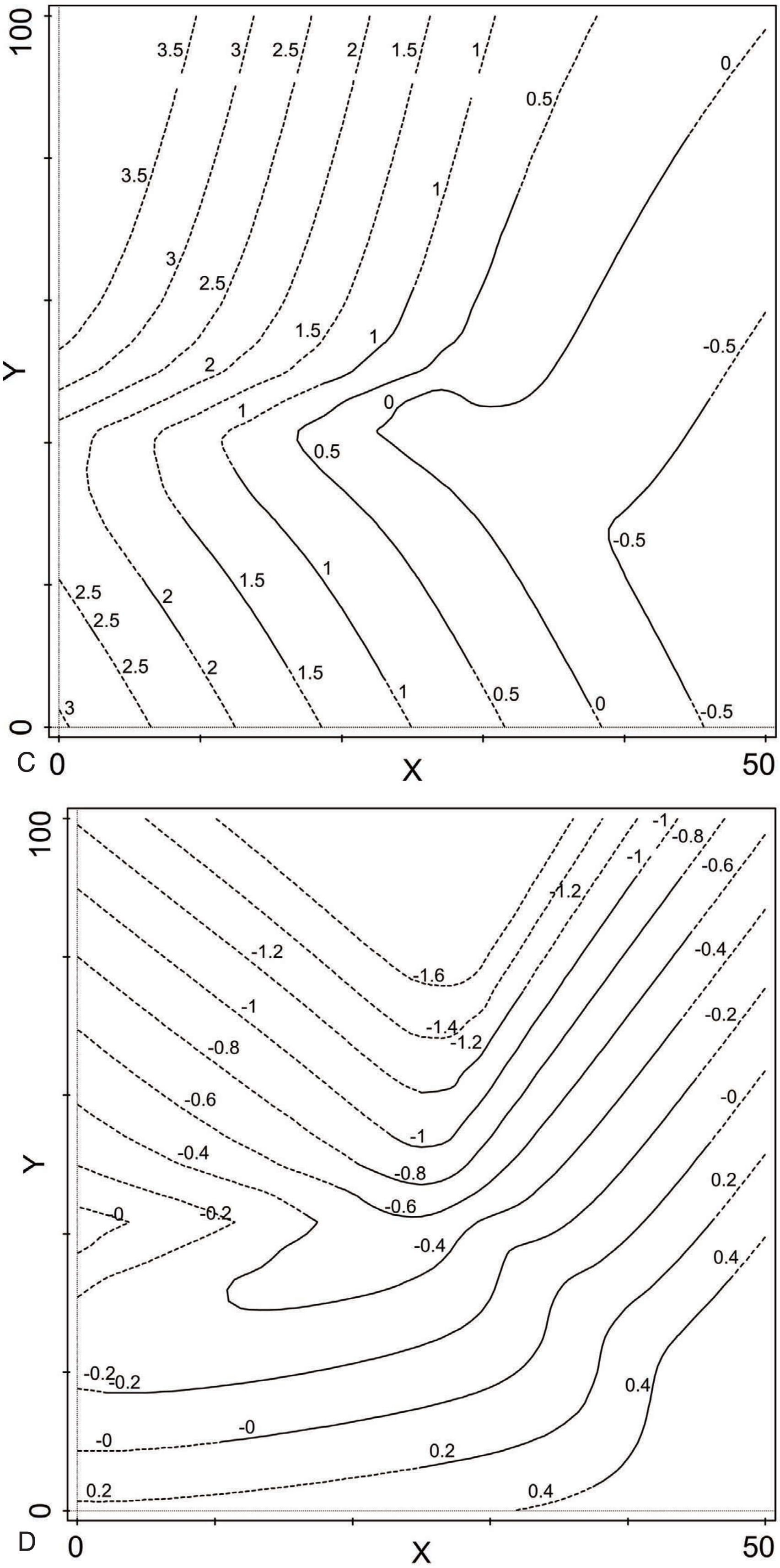


Figure 4.51 C to D: Contour plots derived by a CCA. Axis three is shown in C. Pane D shows axis fout. For interpretation see text on p. 303 and the captions on p. 305.

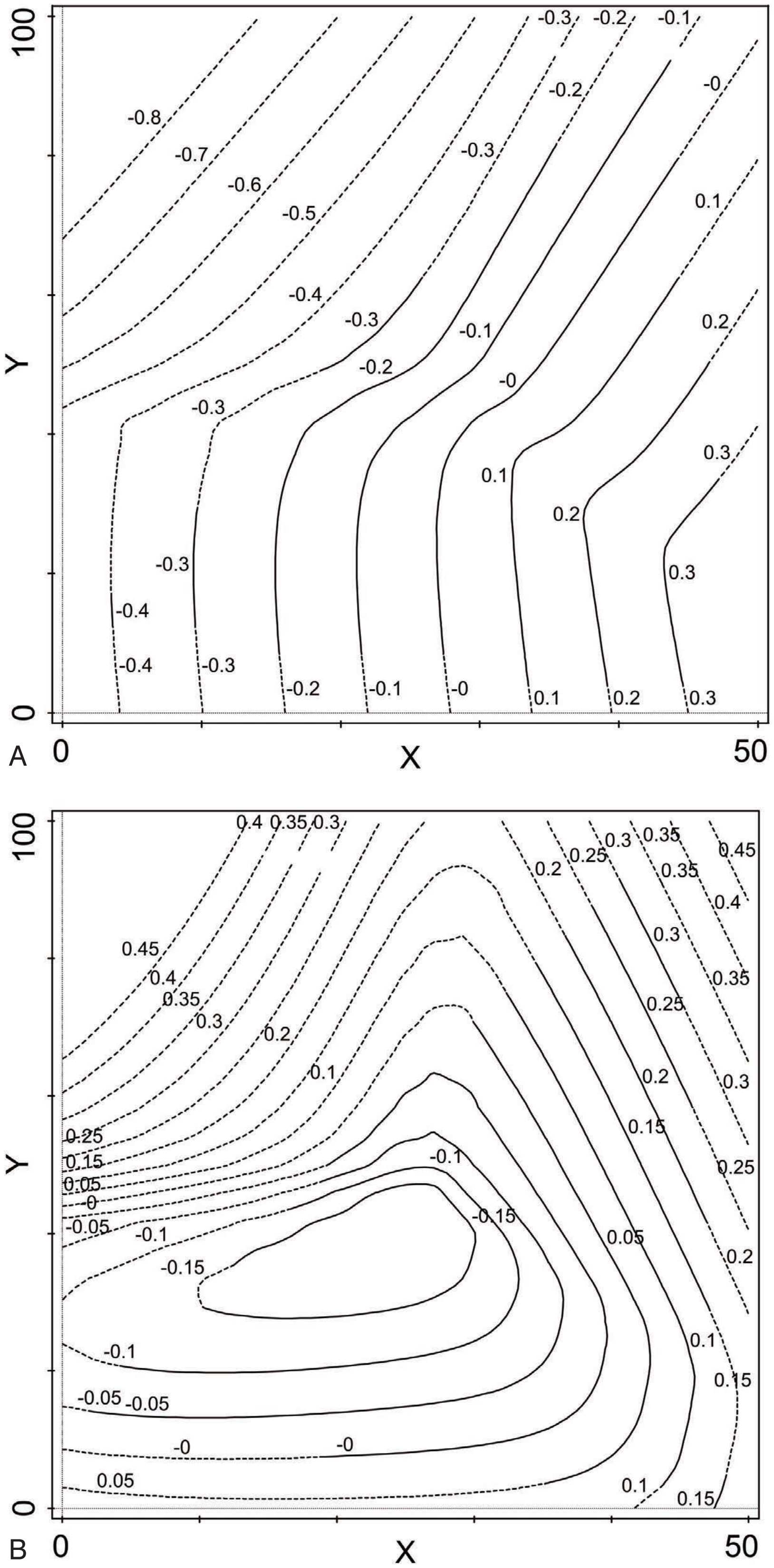


Figure 4.52 A to B: Contour plots of the smoothed changes of the sample scores along the ordination axes derived by a tb-RDA. The analysis and interpretation correspond to that of the CCA. A brief interpretation is given on p. 303 and in the captions on p. 305. The variation explained respectively can be taken from Tab. 4.25.

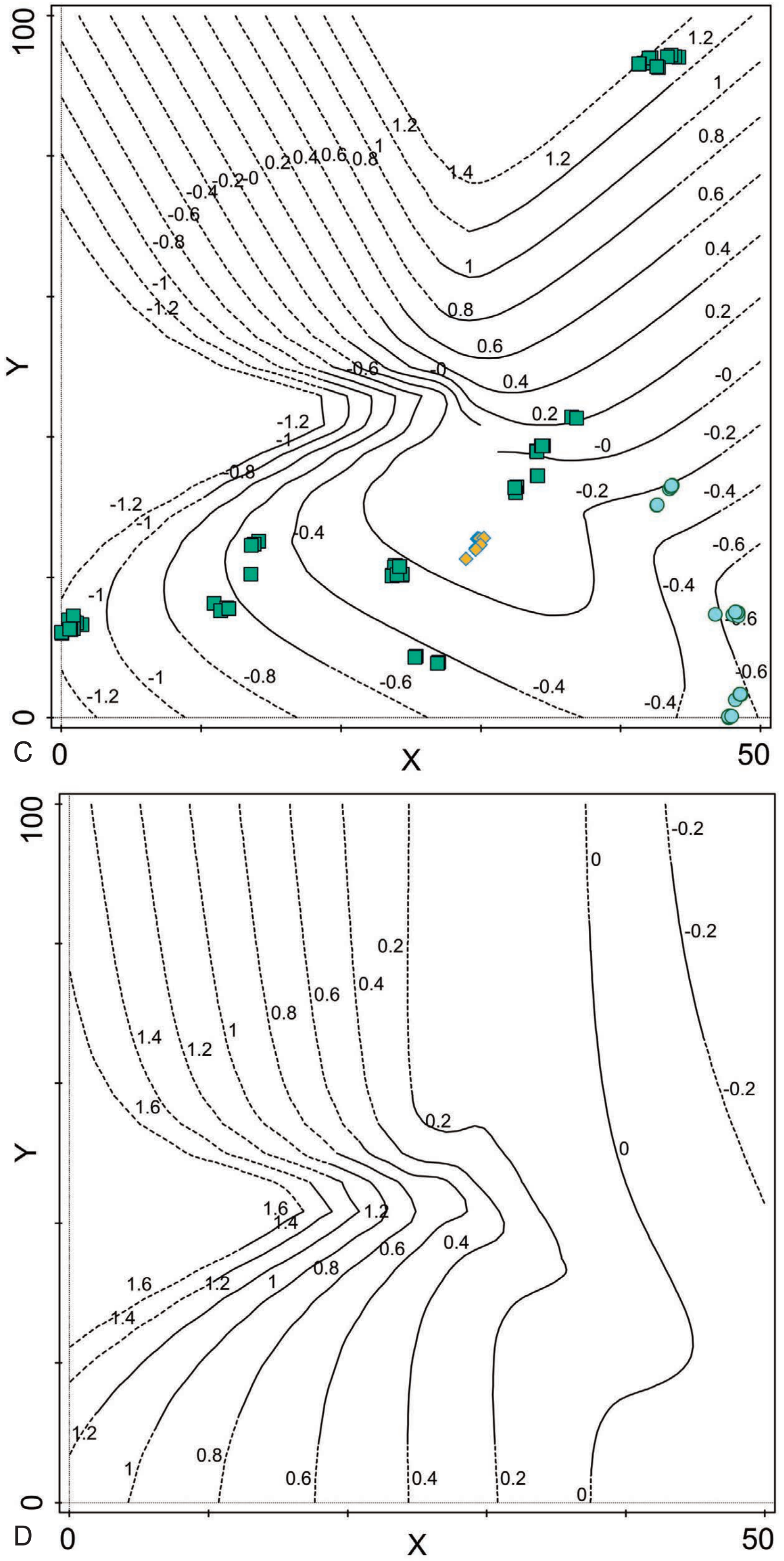
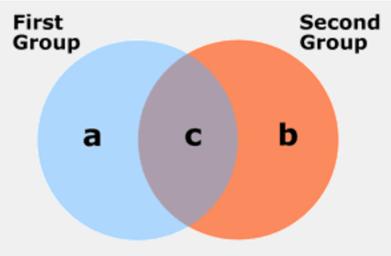


Figure 4.52 C to D: Contour plots of the smoothed changes of the sample scores along the ordination axes derived by a tb-RDA. Axis three is shown in pane C. Here, the sample sites are given for orientation. Axis four is shown in pane D. A brief interpretation is given on page 303.

4.2.5.2 Distance-based Moran’s eigenvector Maps

In order to find more detailed information on all the scales available, variation partitioning in combination with dbMEM was carried out. As a result, the CCA-based approach on partitioning the variation between spatial variables and environmental variables accounts for 21.40% of the variation corrected for false discovery rate. The environmental predictors account for 13.10%, the spatial predictors account for less than 0.10% and the common fraction amounts to 8.20% (see Table 3.26 a-c).

Fraction	Variation(adj)	% of Explained	% of All	DF	Mean Square
a	2.59	61.20	13.10	36.00	0.24
b	0.02	0.40	<0.1	6.00	0.17
c	1.62	38.40	8.20	--	--
Total Explained	4.23	100.00	21.40	42.00	0.27
All Variation	19.735	--	100	90	--



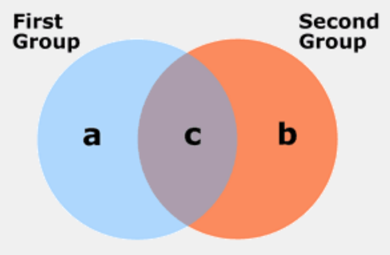
Tested Fraction	F	P
a+b+c	1.6	0.001
a+c	1.7	0.001
b+c	2.4	0.001

Group Members: First Group	Second Group
Precip_a mm	PCO.1
Elev_a_ s_l m	PCO.2
NEAR_DIST	PCO.3
Matrix	PCO.4
Congo_Nile	PCO.5
Ca_Al	PCO.10
Mg_Al	
Soiltype_FAO	
C_N	
pH	
Cat_Geol	

Table 4.26 a - c: Results of a variation partitioning approach with testing for conditional effects of the two groups of explanatory variables based on a CCA. The explanatory power of the single fractions is given in the upper table. The first group (fraction a) contains all the environmental factors s.l. The second group (fraction b) consists of the spatial predictors computed from the X and Y coordinates of the sample sites. The members of the first group were chosen according to the prior analysis. The members of the second group stem from a stepwise interactive forward selection. The statistical significance levels of the single fractions are given in the lower left Table. See Annex 17 for VIFs.

Including all samples and the limitation of the drillable soil depth, the tb-RDA-based approach accounts for 37.70% of the variation in total. While the environmental variables explain 12.20% of the variation, the spatial predictors explain 2.70% and the joint impact explains 22.70%. Therefore, the relatively large share of the joint impact points to spatially structured environmental variables.

Fraction	Variation(adj)	% of Explained	% of All	DF	Mean Square
a	0.12	32.50	12.20	39.00	0.01
b	0.03	7.20	2.70	16.00	0.01
c	0.23	60.30	22.70	--	--
Total Explained	0.38	100.00	37.70	55.00	0.01
All Variation	1	--	100	93	--



Tested Fraction	F	P
a+b+c	2	0.001
a+c	2.3	0.001
b+c	3	0.001

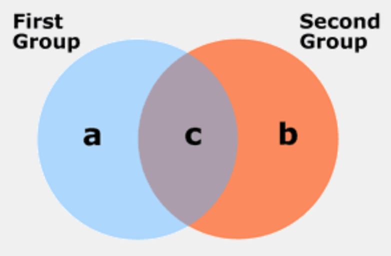
Group Members:	
First Group	Second Group
Precip_a mm	PCO.1
Elev_a_ s_l m	PCO.2
NEAR_DIST	PCO.3
Matrix	PCO.4
Congo_Nile	PCO.5
Mg_Al	PCO.7
Soiltype_FAO	PCO.8
Limitation	PCO.9
C_N	PCO.10
pH	PCO.11
Cat_Geol	PCO.12
	PCO.13
	PCO.15
	PCO.16
	PCO.18
	PCO.24

Table 4.27 a - c: Results of a variation partitioning approach with testing for conditional effects of the two groups of explanatory variables based on a tb-RDA. The explanatory power of the single fractions is given in the upper table. The first group (fraction a) contains all the environmental factors s.l. The second group (fraction b) consists of the spatial eigenfunctions computed from the X and Y coordinates of the sample sites. The members of the first group were chosen according to the prior analysis. The members of the second group stem from a stepwise interactive forward selection. The statistical significance levels of the single fractions are given in the lower left Table. See Annex 18 for VIFs.

So far, the most prominent explanatory variables have been elucidated along with the presence of spatial structures at different scales. Still, some refinement is needed. As has been stated before, there are global trends present in the data on both the X and Y coordinates. Since this trend is known to have an impact on the environmental variables and because the spatial eigenfunctions model finer scales more efficiently (Legendre & Legendre, 2012; Šmilauer & Lepš, 2014), the global trend was removed during further analysis.

As expected, some of the environmental parameters lost explanatory power and some diminished in their explanatory value. Again, both approaches, the linear tb-RDA-based and the unimodal one based on CCA, have been taken. The unimodal model made it possible to explain 20.50%$_{adj}$ of the variation, of which 10.60%$_{adj}$ are attributed to the environmental variables, 2.10%$_{adj}$ to the spatial predictors and 7.90%$_{adj}$ to the joint impacts. However, the larger percentage explained by the environmental predictor has to be relativised. Table 4.28 shows that the variation explained per one constrained axis (i.e., per degree of freedom) is only slightly smaller for the spatial predictors.

Fraction	Variation(adj)	% of Explained	% of All	DF	Mean Square
a	1.98	51.40	10.60	35.00	0.22
b	0.38	10.00	2.10	11.00	0.19
c	1.48	38.60	7.90	--	--
Total Explained	3.85	100.00	20.50	46.00	0.25
All Variation	**18.746**	--	**100**	**88**	--



Tested Fraction	F	P
a+b+c	1.5	0.001
a+c	1.6	0.001
b+c	1.9	0.001

Group Members:	
First Group	Second Group
Precip_a mm	PCO.1
Elev_a_ s_l m	PCO.3
NEAR_DIST	PCO.4
Matrix	PCO.5
Congo_Nile	PCO.6
Mg_Al	PCO.7
Soiltype_FAO	PCO.8
C_N	PCO.10
pH	PCO.14
Cat_Geol	PCO.15
	PCO.18

Table 4.28 a - c: Results of a variation partitioning approach with testing for conditional effects of the two groups of explanatory variables based on a partial CCA. The effect of the trend represented by the X and Y coordinates of the sample sites has been removed prior to further analysis. The explanatory power of the single fractions is given in the upper table. The first group (fraction a) contains the environmental factors s.l. chosen in the prior analyses. The second group (fraction b) consists of the spatial predictors computed from the X and Y coordinates of the sample sites. The members of the first group were chosen according to the prior analysis. The members of the second group stem from a stepwise interactive forward selection. The statistical significance levels of the single fractions are given in the lower left Table. See Annex 19 for VIFs.

When examining the scatter plots, interpretability becomes very low. Along the second axis, the [Mg]:[Al] ratio has kept most of its impact. Along the first and second axis, the [C]:[N] ratio offers some explanatory value. However, inference from this plot will be in error, as the samples from Cyamudongo Forest exhibit some of the lowest values on said ratio. An erroneous judgement would also be made on sample 56C since its real amount of precipitation received annually is right in the middle of the spectrum. Further inferences from the graphs would be dubious, to say the least. Since the impact of the environmental factors has been explicated by the above analyses and, moreover, the spatial component of the variation in species composition is the focus of our interest here, the biplots are only shown as exemplary.

While the set of environmental variables was kept as found during the preceding CCAs, the spatial predictors had to be chosen via interactive stepwise forward selection. The representations of the spatial eigenfunctions are given as smoothed contour plots for each PCO.n in XY coordinate space to summarise the patterns of the constrained sample scores along the respective PCO axes. The Graphs in Fig. 4.54 show the 11 spatial eigenfunctions with positive spatial correlations selected from the dbMEM analysis. The definition of the subsets corresponding to the different spatial scales is arbitrary and, as can be seen for the medium-scale, not without difficulties. The spatial eigenfunctions PCO.1 and PCO.3 clearly show a broad scale change with little to no variation within Nyungwe Forest. PCO.4 and PCO.5 still show broad-scale change along the Y axis, and they also include some change on the X axis, setting apart the eastern and western parts of the forest. The same result is valid for PCO.6 and PCO.7. The spatial predictors PCO.8 and PCO.10 show some medium-range patterns that separate the eastern and western part of Nyungwe Forest. The eigenfunctions PCO.14 and PCO.15 model comparable patterns on a slightly finer scale, while PCO.18 models the finest significant scale in this analysis. Here, continuously changing patterns in both directions are visible.

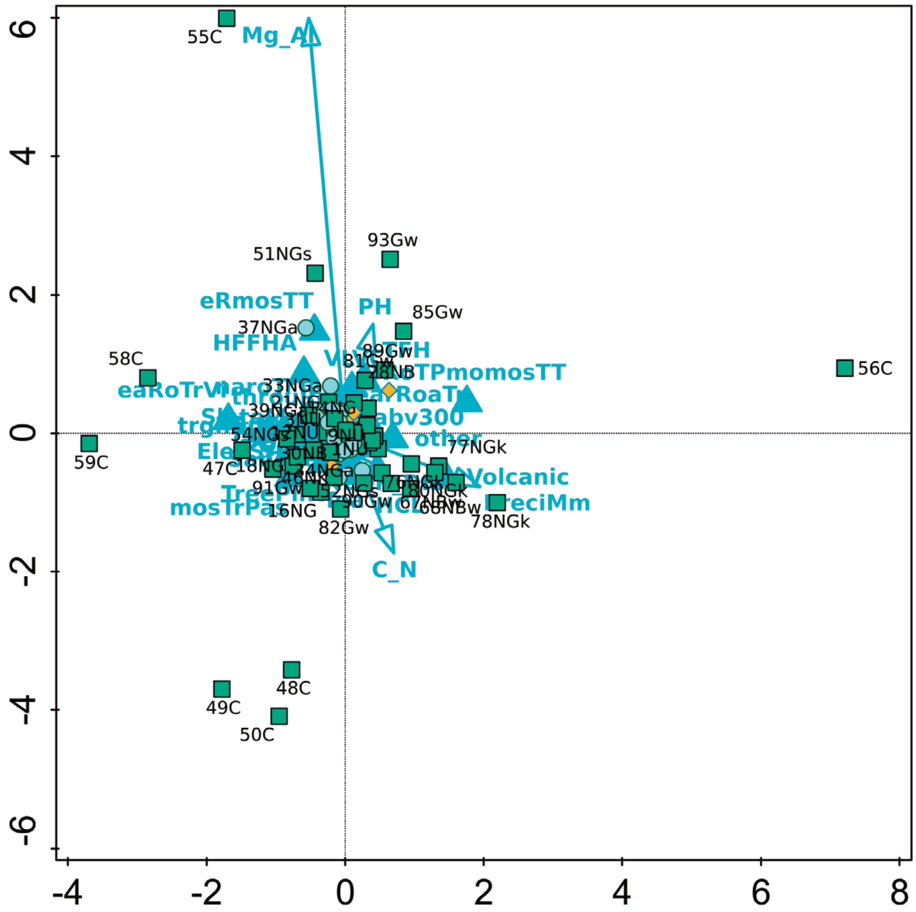


Figure 4.53: Biplot depicting the results of a variation partitioning approach based on a partial CCA. The environmental variables s.l. and the spatial predictors derived from the X and Y coordinates of the samples were used to build the two groups of explanatory variables, respectively. The interpretation of the graph (here axes one and two) is rather complicated and false inferences are likely to be drawn. The plots representing axes three are subject to the same difficulties and are not shown.

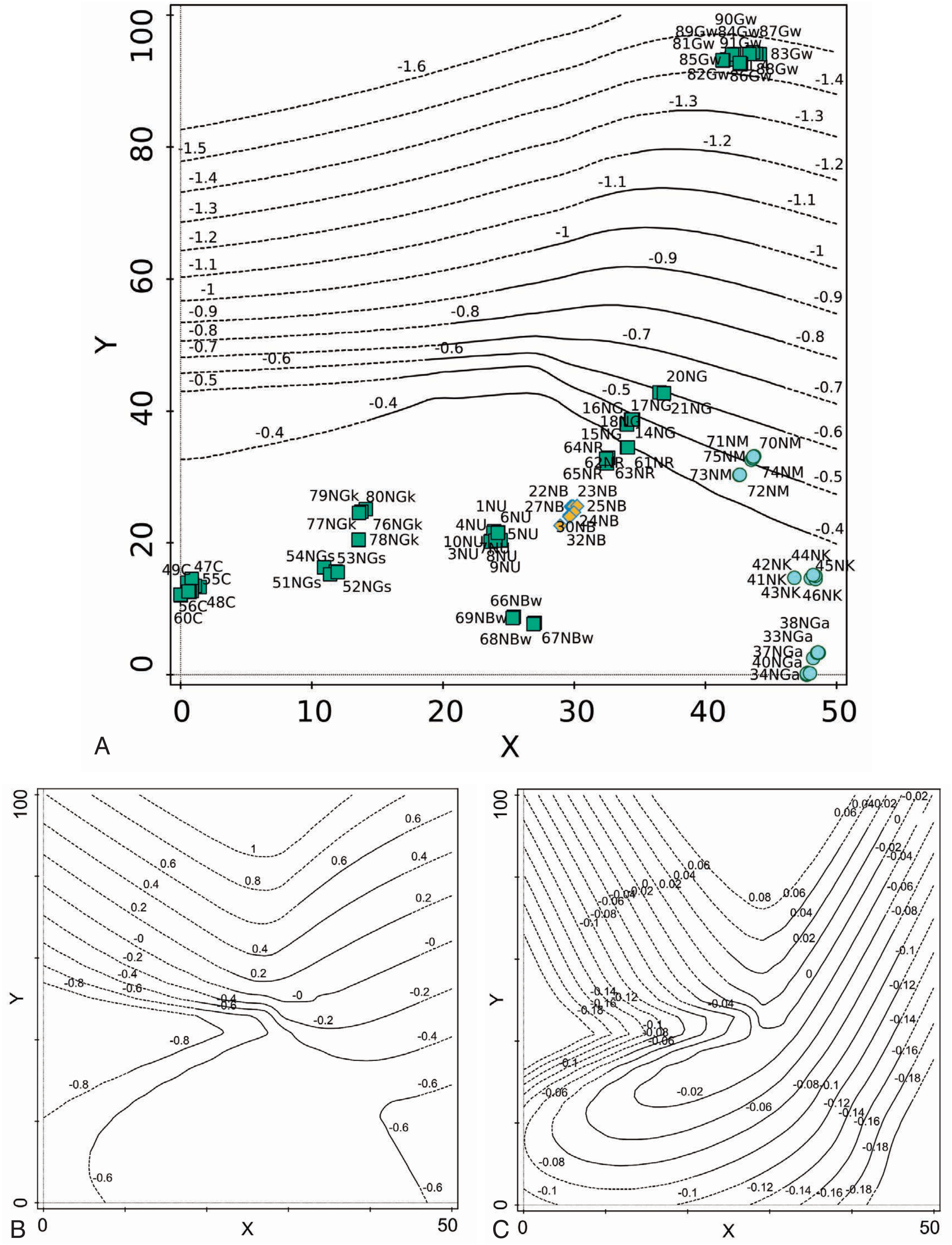


Figure 4.54 A-K: Smoothed contour plots of the constrained case scores representing the effects of the spatial eigenfunctions picked during forward selection. The analysis is based on a partial CCA using the XY coordinates as covariates, i.e., partialling out the global trend. Panes A to F depict the case scores illustrating the effects of the broad scale spatial predictors (see text for interpretation) PCO.1, PCO.3, PCO.4, PCO.5, PCO.6 and PCO.7, respectively. The effects of the spatial predictors deemed to represent medium scale changes are shown in panes G-J. These comprise: PCO.8, PCO.10, PCO.14 and PCO.15. The fine scale appears to be represented by PCO.18 and is given in pane K.

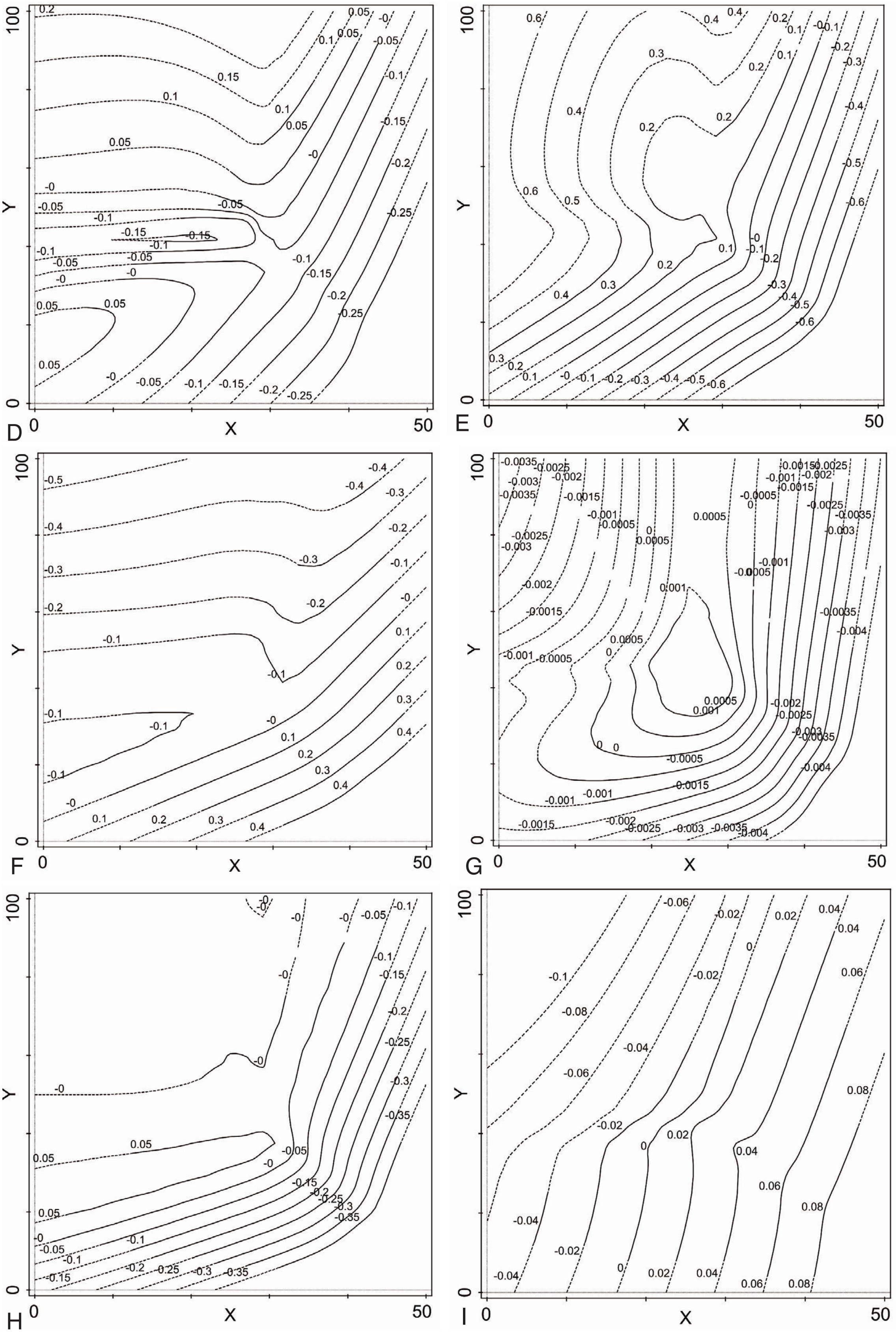


Figure 4.54 D-I: Smoothed contour plots representing the effects of the spatial eigenfunctions as used in a CCA. Panes D to F depict the effects of the broad scale spatial-predictors PCO.5, PCO.6 and PCO.7, respectively. Panes G to I show the effects of the medium-scale predictors PCO.8, PCO.10 and PCO.14, respectively.

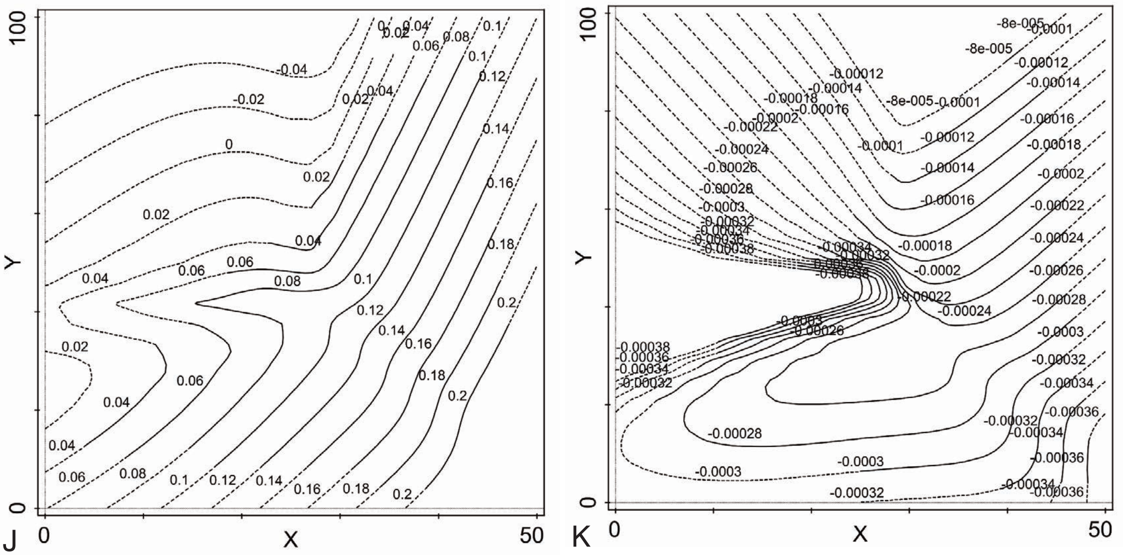


Figure 4.54 J-K: Smoothed contour plots representing the effects of the spatial eigenfunctions as used in a CCA. Pane J depicts the effect of the medium-scale spatial predictors PCO.15. Pane K shows the effect of the fine-scale predictor PCO.18.

With the same procedure, but using transformation based redundancy analysis as premise, 33.90%$_{adj}$ could be explained. The environmental variables account for 13.10%$_{adj}$ of the variation, the spatial predictors for 3.80%$_{adj}$ while the joint effect amounts to 17.00%$_{adj}$. Though interpretation of the graphs seems easier on first sight, the same caution and reference to the measured values are indispensable. Of the 24 spatial predictors computed, 14 remained significant during the interactive stepwise forward selection (Tab. 4.29 c; Fig. 4.56 A to M. The solely spatial effect is small, as has been stated. The common fraction constitutes more than half of the overall impact.

Fraction	Variation(adj)	% of Explained	% of All	DF	Mean Square
a	0.12	38.60	13.10	39.00	0.01
b	0.03	11.20	3.80	14.00	0.01
c	0.15	50.20	17.00	--	--
Total Explained	0.31	100.00	33.90	53.00	0.01
All Variation	0.91073	--	100	91	--

Tested Fraction	F	P
a+b+c	1.9	0.001
a+c	2	0.001
b+c	2.7	0.001

Table 4.29 a - c: Results of a variation partitioning approach with testing for the conditional effects of the two groups of explanatory variables based on a partial tb-RDA. The effect of the trend represented by the X and Y coordinates of the sample sites has been removed prior to further analysis. The explanatory power of the single fractions is given in the upper table. The first group (fraction a) contains the environmental factors s.l. The second group (fraction b) consists of the spatial predictors computed from the XY coordinates of the sample sites. Interpretation follows the same principles as for CCA above. VIFs in Annex 20.

Group Members:	
First Group	Second Group
Precip_a mm	PCO.1
Elev_a_ s_l m	PCO.2
NEAR_DIST	PCO.3
Matrix	PCO.4
Congo_Nile	PCO.5
Mg_Al	PCO.7
Soiltype_FAO	PCO.8
Limitation	PCO.11
C_N	PCO.12
pH	PCO.15
Cat_Geol	PCO.16
	PCO.18
	PCO.20
	PCO.24

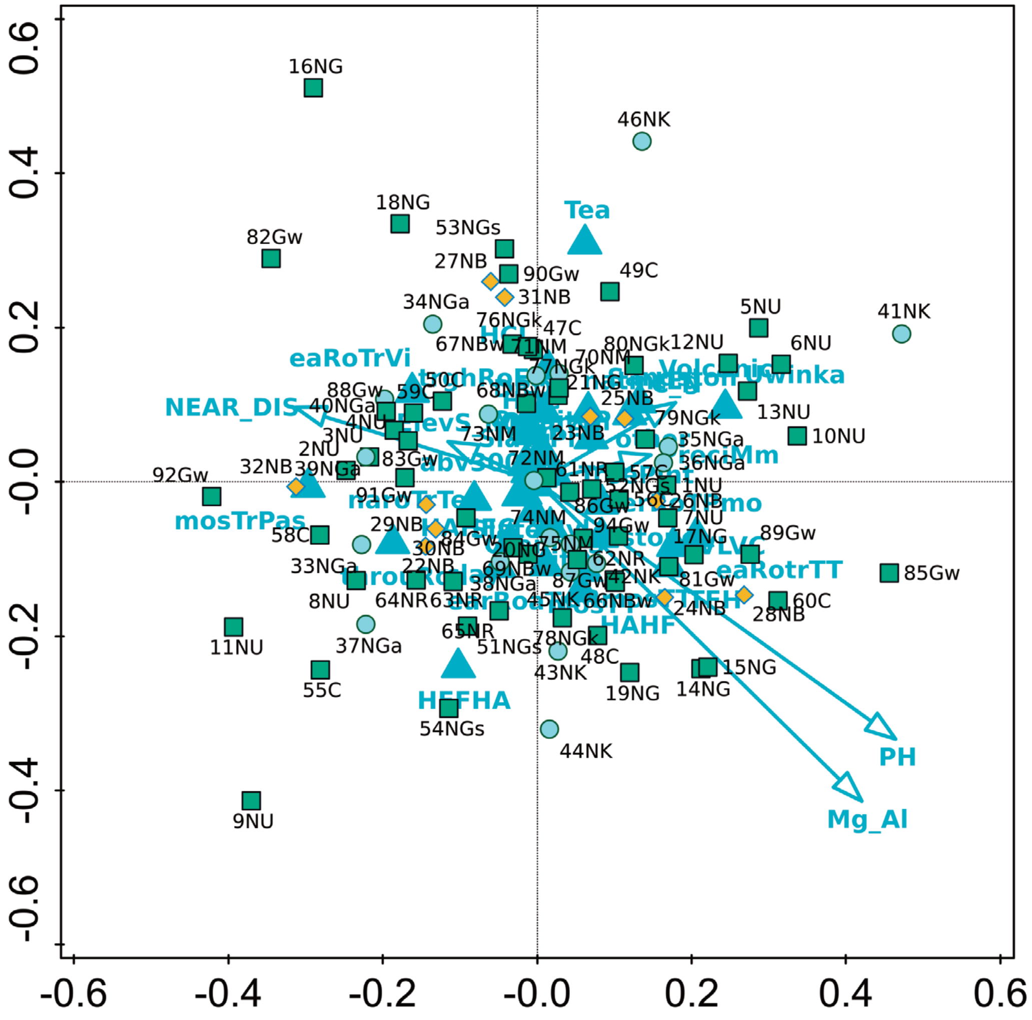


Figure 4.55: Biplot depicting the results of a variation partitioning approach based on a partial tb-RDA. The environmental variables s.l. and the spatial predictors derived from the X and Y coordinates of the samples were used to build the two groups of explanatory variables, respectively. The interpretation of the graph (here axes one and two) appears to be more straightforward than the corresponding graph dervied from CCA, yet false inferences are likely to be drawn. The plots representing axes three are subject to the same difficulties and are not shown.

Like in the unimodal model, PCO.1 to PCO.3 model broad-scale spatial variation displaying mainly the differences between Gishwati and Nyungwe Forest. Modelling likewise coarse variation, PCO.4 and PCO.5 display a structure with a change from east to west. For PCO.7, the scale on which the differences in both directions are shown seems to be at the upper end of the medium range. The spatial predictor PCO.8 exhibits, at a medium level, some variation between the north and the south of the research area. Again—a predictor—PCO.11 showing differences between east and west, is positioned at the upper end of the medium scale. Separating Cyamudongo Forest, PCO.12 displays a medium spatial pattern, while PCO.15 and PCO.16 demonstrate the same behaviour but on a yet finer scale. On a still finer scale, PCO.18 and PCO.20 separate all forests. While PCO.24 still shows a gradual change from north to south and from east to west the scale clearly allows for the conjecture that at the local scale, i.e., the ranger posts if at all only very little change occurs. The reason here maybe spatial autocorrelation or responses to ecological processes not yet found.

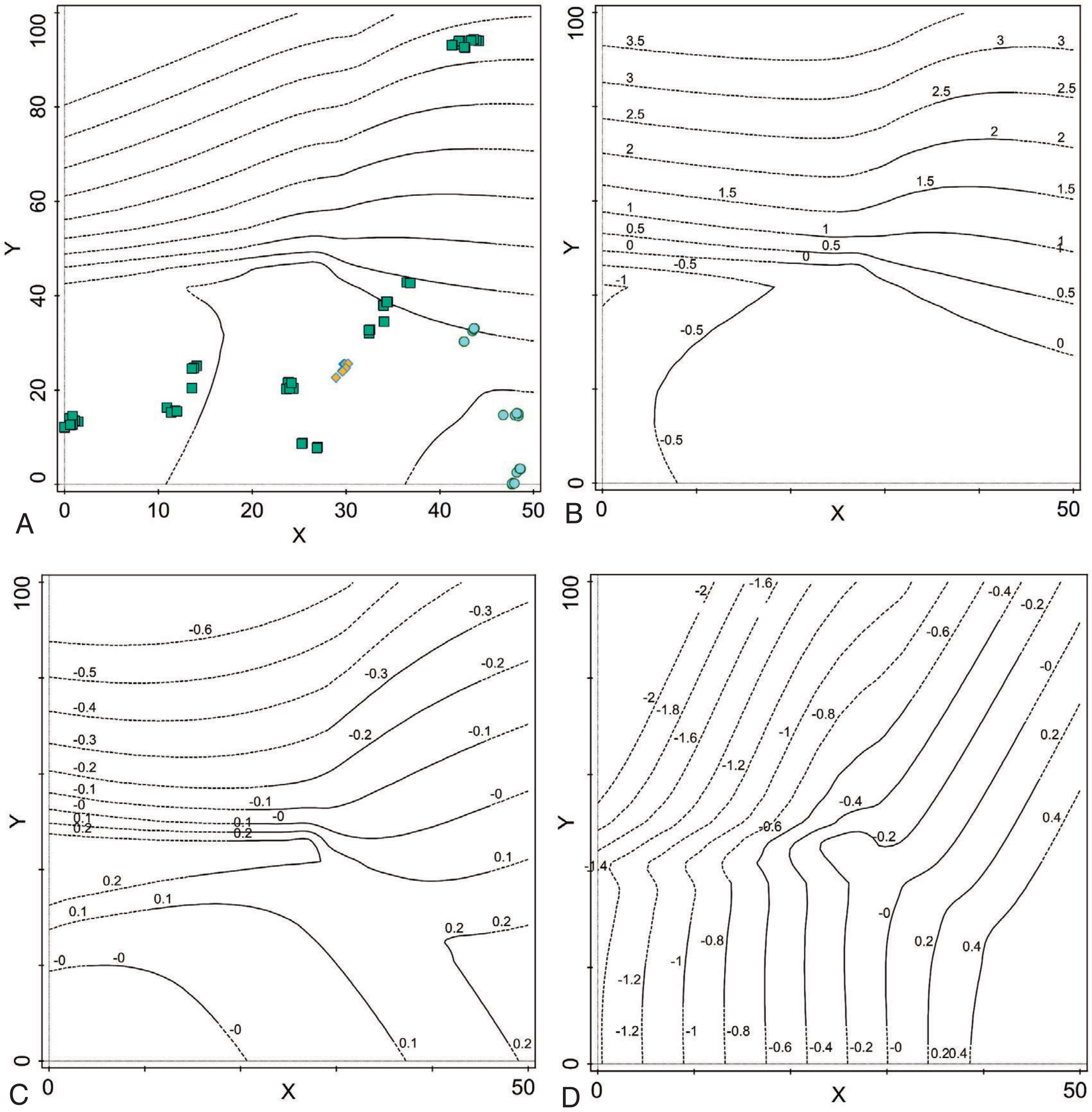
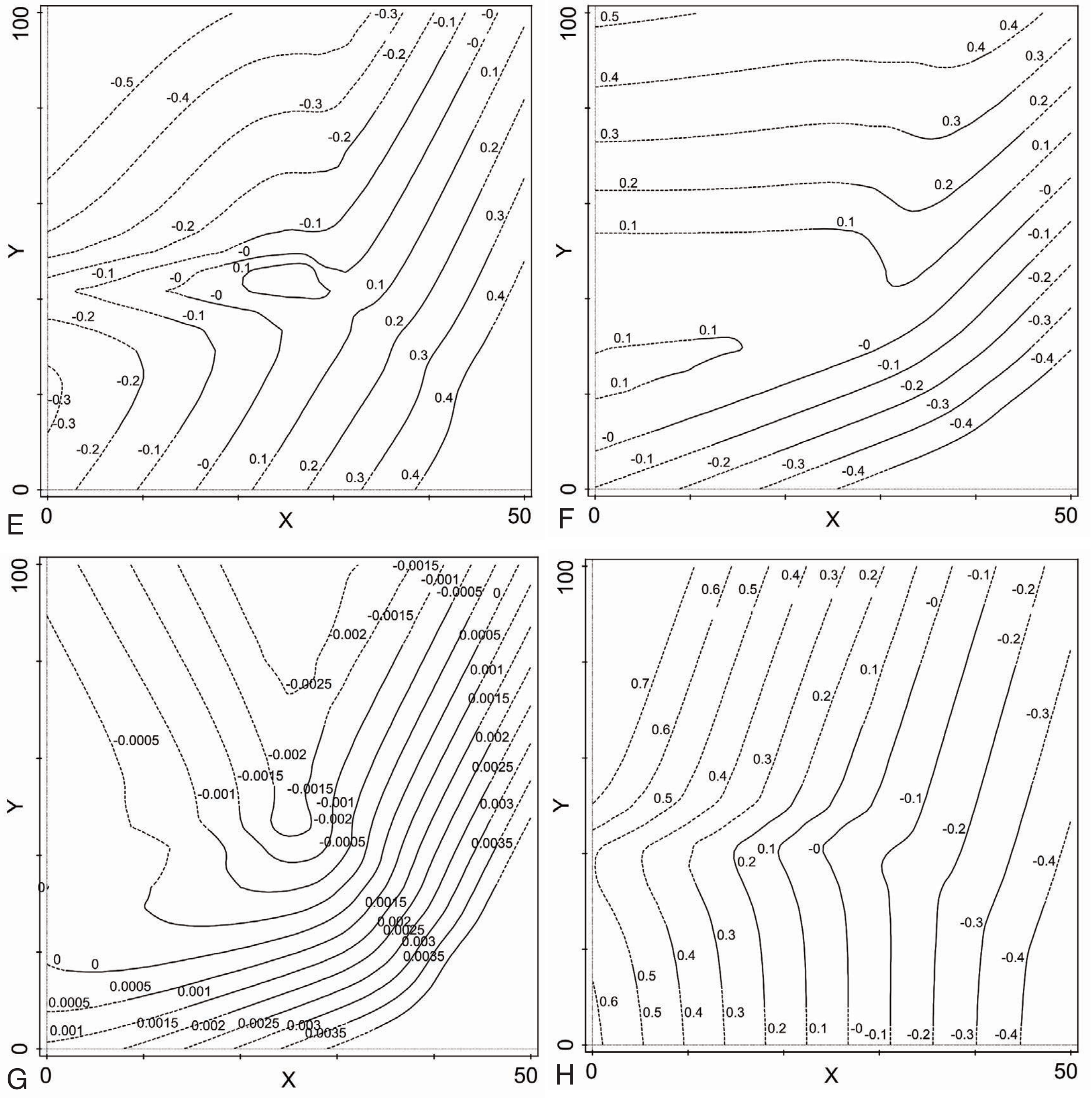


Figure 4.56 A-D: Smoothed contour plots of the constrained case scores representing the effects of the spatial eigenfunctions picked during forward selection. The analysis is based on a partial tb-RDA. The X and Y coordinates of the sample plots were used as covariates. Panes A to E depict the effects of the broad-scale spatial predictors PCO.1 to PCO.5.



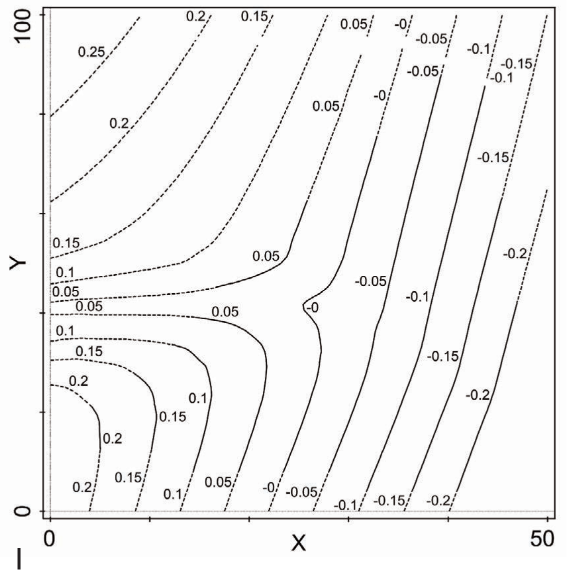


Figure 4.56 A-M: Smoothed contour plots of the constrained case scores representing the effects of the spatial eigenfunctions picked during forward selection. The analysis is based on a partial tb-RDA. The X and Y coordinates of the sample plots were used as covariates. Panes A to E depict the case scores illustrating the effects of the broad-scale spatial predictors (see text for interpretation) PCO.1 to PCO.5. PCO.7 to PCO.15 represent the medium level of spatial variation (panes F to J). While the overall range of the scale is deemed medium, the scale becomes increasingly finer towards PCO.15. Due to some unknown technical reason, PCO.16 could not be graphed. The fine scale appears to be represented by PCO.18 and PCO.20 (panes K and L). The variation represented by PCO.24 is given in pane M and illustrates a very fine-scaled change. For interpretaion see also the text.

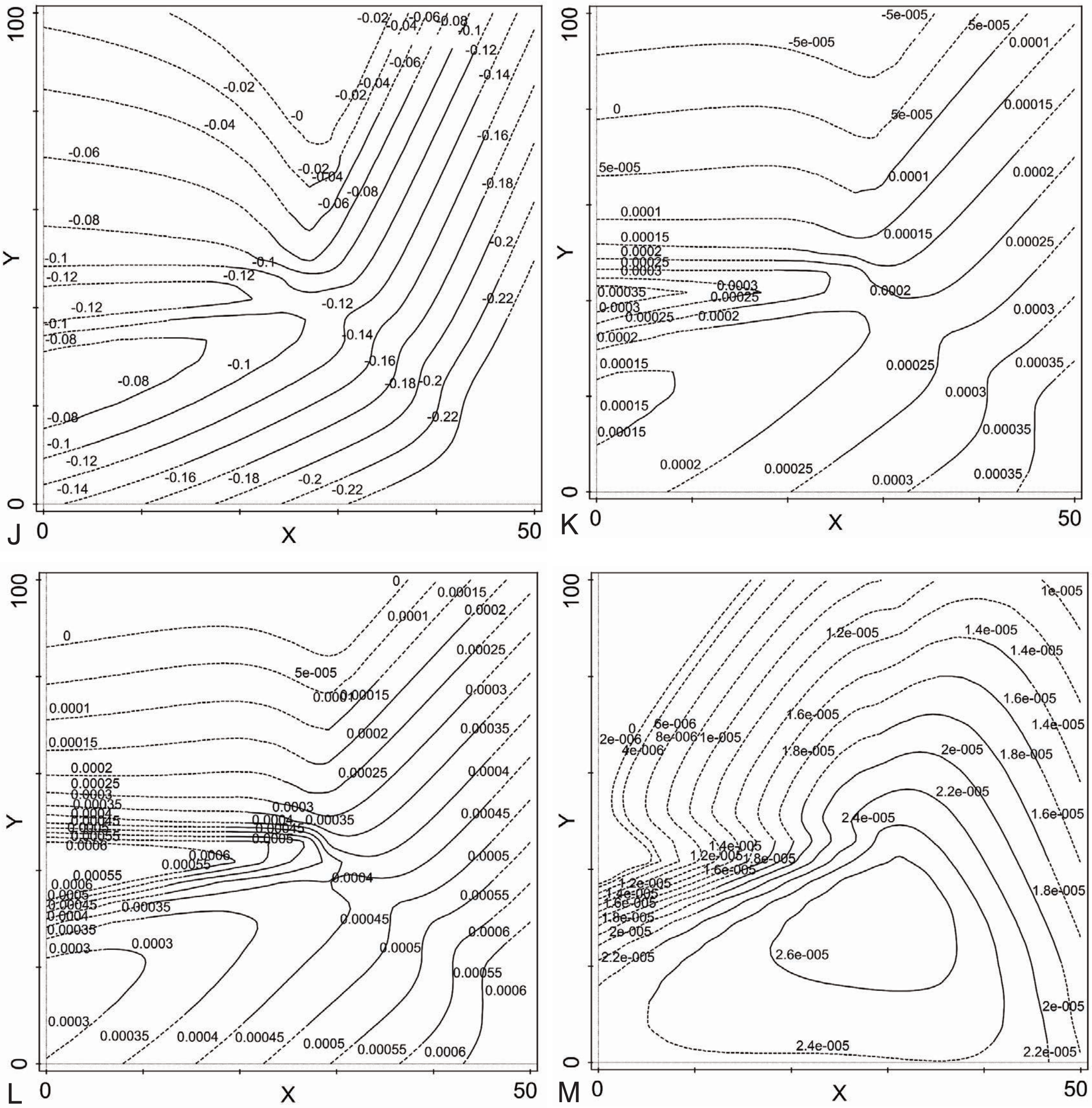


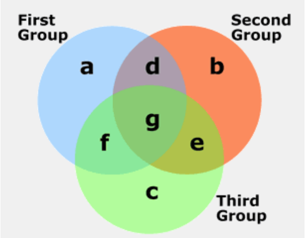
Figure 4.56 J-M: Smoothed contour plots of the constrained case scores representing the effects of the spatial eigenfunctions picked during forward selection. The analysis is based on a partial tb-RDA. The X and Y coordinates of the sample plots were used as covariates. Pane J depicts the effect of spatial predictor PCO.15. Panes K to M depict the effects of the fine-scale spatial predictors PCO.18, PCO.20 and PCO.24.

With the spatial predictors chosen during the above procedure, yet another variation partitioning has been undertaken. The first one is based on tb-RDA. This time with three groups between which the conditional effects have been tested. All of the groups explain 37.80%$_{\text{adj}}$ of the variation in a joint manner. At this point it is necessary to remind of the underlying global spatial trend, that was removed during the above analyses. For the current analysis, Canoco 5 does not offer the option to detrend the data prior. Thus, the results provided in the following still contain the global trend which will be represented by one or a few of the spatial predictors from the third group and very likely by larger shares of the spatially structured explanatory variables.

The environmental variables only explain 6.20%$_{\text{adj}}$ of the variation on their own. Again, the explanatory variables describing soil conditions outweigh the explanatory power of the environmental variables. The part shared by both has become quite small as has the part exclusive to spatial phenomena. The spatial predictors share explanatory power with the soil components to a relatively large extent, giving the fourth largest share. This is followed by the joint impact of environmental variables and space. The fraction jointly shared by all of them amounts to $10.40\%_{adj}$.

Since up to this point, the explanatory variables have been chosen based on the preceding results and the presence of correlations between the single variables already has been established, an even more parsimonious set of explanatory variables was sought. Therefore, a second approach was also run with a new forward selection before calculating the respective fractions of explained variation. Explanatory power only changed slightly, as did the respective shares. The respective common fractions explained by the environmental, soil and spatial variables (fractions e, f and g) increased. Since more spatial predictors entered the analysis by forward selection, no clear statement is possible if the respective joint fractions increased only because the number of descriptors increased or if indeed, further spatial structures have been discovered. Following Šmilauer & Lepš (2014), the interpretation of contiguous spatial predictors is not without uncertainties, and since merely adjoining predictors entered the analysis, inferences have to be made with care. In the end, total explanatory power decreased marginally, while statistical significance increased marginally after employing a new forward selection (Results see Annex 21).

Fraction	Variation(adj)	% of Explained	% of All	DF	Mean Square
a	0.06	16.50	6.20	19.00	0.01
b	0.07	19.40	7.40	19.00	0.01
c	0.03	7.50	2.90	14.00	0.01
d	0.03	6.90	2.60	--	--
e	0.046526	12.3	4.7	--	--
f	0.04	9.80	3.70	--	--
g	0.10	27.60	10.40	--	--
Total Explained	0.38	100.00	37.80	52.00	0.01
All Variation	1.00	--	100.00	93.00	--



Group Members:		
First Group	Second Group	Third Group
Precip_a mm	Mg_Al	PCO.1
Elev_a_ s_l m	Soiltype_FAO	PCO.2
Matrix	Limitation	PCO.3
Congo_Nile	C_N	PCO.4
	pH	PCO.5
	Cat_Geol	PCO.7
		PCO.8
		PCO.11
		PCO.12
		PCO.15
		PCO.16
		PCO.18
		PCO.20
		PCO.24

Tested Fraction	F	P
a+b+c+d+e+f+g	2.1	0.001
a	1.3	0.002
b	1.4	0.001
c	1.2	0.017
a+d	1.5	0.001
b+e	1.7	0.001
c+f	1.5	0.001

Table 4.30 a - c: Results of a variation partitioning approach with testing for the conditional effects of independent variables. The explanatory power of the single fractions is given in the upper table. The first group (fraction a) contains the environmental factors. The second group (fraction b) consists of the soil variables and the third group (fraction c) contains the spatial eigenfunctions computed from the X and Y coordinates of the sample sites. Interpretation follows the same principles as for CCA above. See Annex 22 for VIFs.

Not surprisingly, taking into account the spatial predictors and hence a spatial structure, the distance to the forest edge contributed greatly to the variance inflation factors. Removing the distance to the forest edge during a forward selection led to a drop in explanatory power of 1.20%, but much reduced the effect of multicollinearity. Removing the forest edge distance subsequently from the variation partioning approach testing for the conditional effects of the variables chosen, lead to no change in over-all variation explained. While the order of fractions explained by the respective variables and their combined effects remained the same, variance inflation factors greatly reduced making the solution more stable (TER BRAAK & ŠMILAUER, 2012).

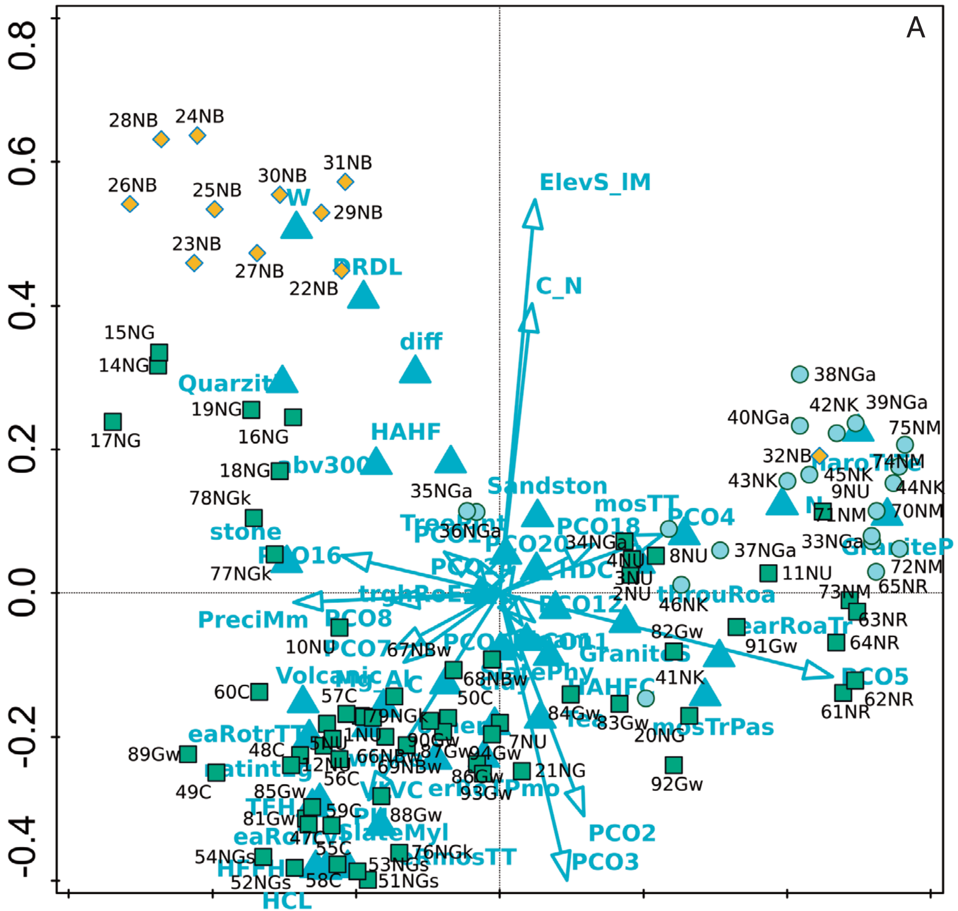


Figure 4.57 A-C: Biplot as a result of variation partitioning using tb-RDA. The partitioning approach was carried out using three groups of explanatory variables. The first group consists of the environmental variables s. str. Following a new forward selection taking the simple effects into account, the distance to the forest edge was left out. Based on this result, the distance to the forest edge was also omitted in the current analysis, which tests for the conditional effects. The second group contains the soil parameters. The third group comprsises the spatial eigenfunctions. Due to limitations in the set-up of the analysis, the global trend is still persent in the data analysed. (For a detrended approach, see the partitioning analysis above.) Pane A of the current figure shows axis one and axis two. The resolution of the plot seems to be quite high, yet interpretation should proceed with caution. See the text for interpretation.

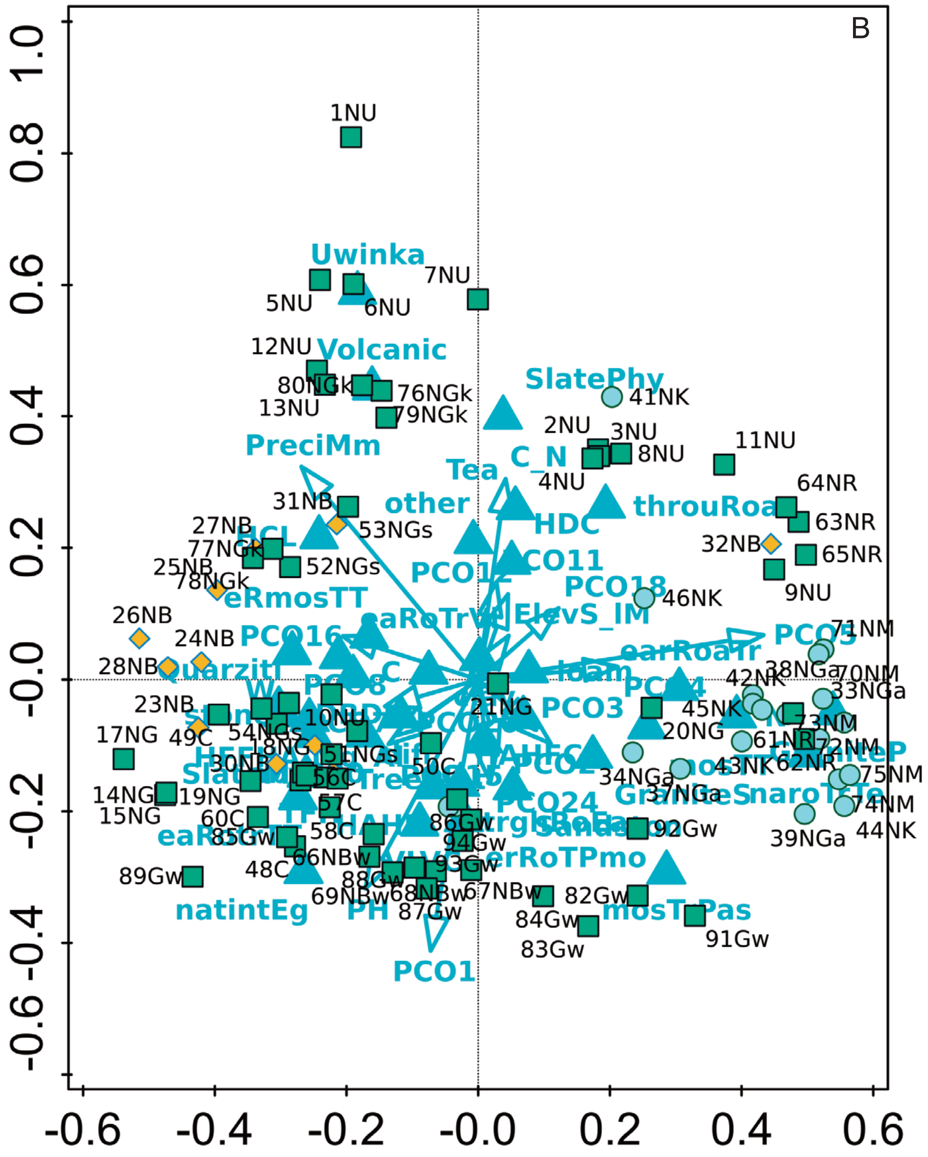


Figure 4.57 B: Biplot as a result of variation partitioning using tb-RDA. The partitioning approach was carried out using three groups of explanatory variables. Pane B depicts axes one and three. See text and captions for pane A for interpretation.

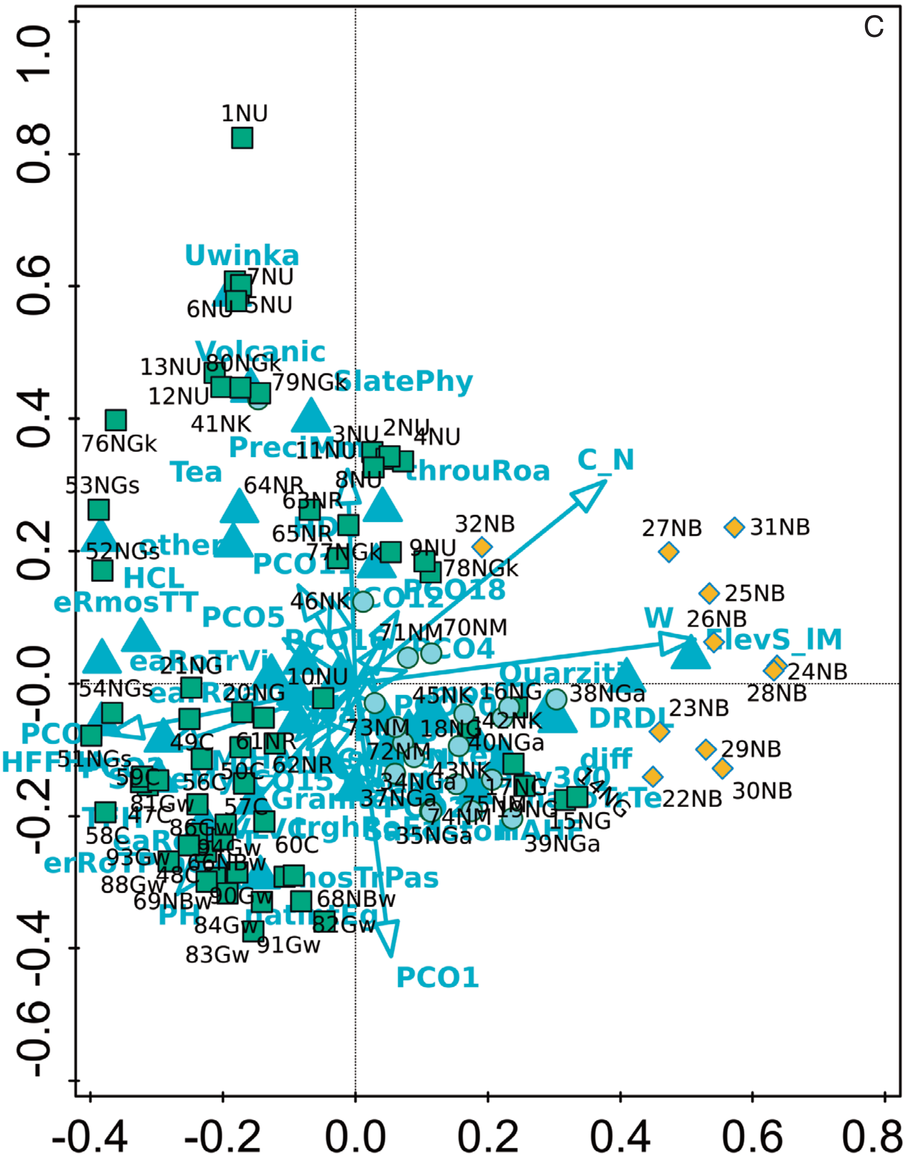
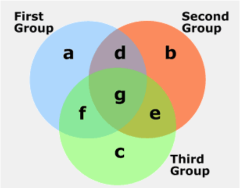


Figure 4.57 B: Biplot as a result of variation partitioning using tb-RDA. The partitioning approach was carried out using three groups of explanatory variables. Pane C depicts axes two and three. See text and captions for pane A for interpretation.

The model stemming from the unimodal approach has been tested correspondingly. Utilising the variables exemplified above, the test for conditional effects resulted in an explained variation of 22.60%$_{adj}$; while the explanatory power of the environmental variables dropped to almost negligible 2.10%$_{adj}$ and the statistical significance also dropped below the 95% threshold. Eight percent of the variation could be explained by the remaining soil variables alone. The common fractions of environmental, soil and spatial variables (groups d-f) constitute the largest fraction of explained variation. Pursuing a new forward selection, the distance to the forest margin dropped out of the analysis as well as some spatial predictors. The variation which could be explained by all groups of explanatory variables thus summs up to 21.70%$_{adj}$ (results see Annex 23). Since the variation partitioning template with forward selction offered by Canoco 5 only considers the simple effects of the independent variables, a consequtive analysis was carried out taking the conditional effects of the groups of independent variables into account. As with tb-RDA before, the distance to the forest edge was omitted. In difference to the tb-RDA approach the overall explanatory power increased slightly to 22.90%. At the same time, the VIFs were reduced rendering the result more reliable. While the percentage of variation explained by fraction a increased to 2.4%adj, the statistical significance remained below 95% with P = 0.116. The percentages of explained variation for the remaining fractions changed only slightly, and the common fractions still account for the largest share to the environmentally determined variation in species composition.

Fraction	Variation(adj)	% of Explained	% of All	DF	Mean Square
a	0.47	10.30	2.40	18.00	0.19
b	1.61	35.70	8.20	17.00	0.23
c	0.29	6.40	1.50	10.00	0.19
d	0.77	17.10	3.90	--	--
e	0.70229	15.6	3.6	--	--
f	0.59	13.00	3.00	--	--
g	0.09	1.90	0.40	--	--
Total Explained	4.52	100.00	22.90	45.00	0.27
All Variation	19.74	--	100.00	90.00	--



Group Members:		
First Group	Second Group	Third Group
Precip_a mm	Ca_Al	PCO.3
Elev_a_ s_l m	Mg_Al	PCO.4
Matrix	Soiltype_FAO	PCO.5
Congo_Nile	C_N	PCO.6
	pH	PCO.7
	Cat_Geol	PCO.8
		PCO.10
		PCO.14
		PCO.15
		PCO.18

Tested Fraction	F	P
a+b+c+d+e+f+g	1.6	0.001
a	1.1	0.116
b	1.4	0.002
c	1.1	0.156
a+d	1.3	0.001
b+e	1.6	0.001
c+f	1.4	0.001

Table 4.31 a - c: Results of a variation partitioning approach with testing for the conditional effects of independent variables. The explanatory power of the single fractions is given in the upper table. The first group (fraction a) contains the environmental factors. The second group (fraction b) consists of the soil variables and the third group (fraction c) contains the spatial eigenfunctions computed from the X and Y coordinates of the sample sites. Interpretation follows the same principles as for variation partitioning with two groups above. For VIFs see Annex 24.

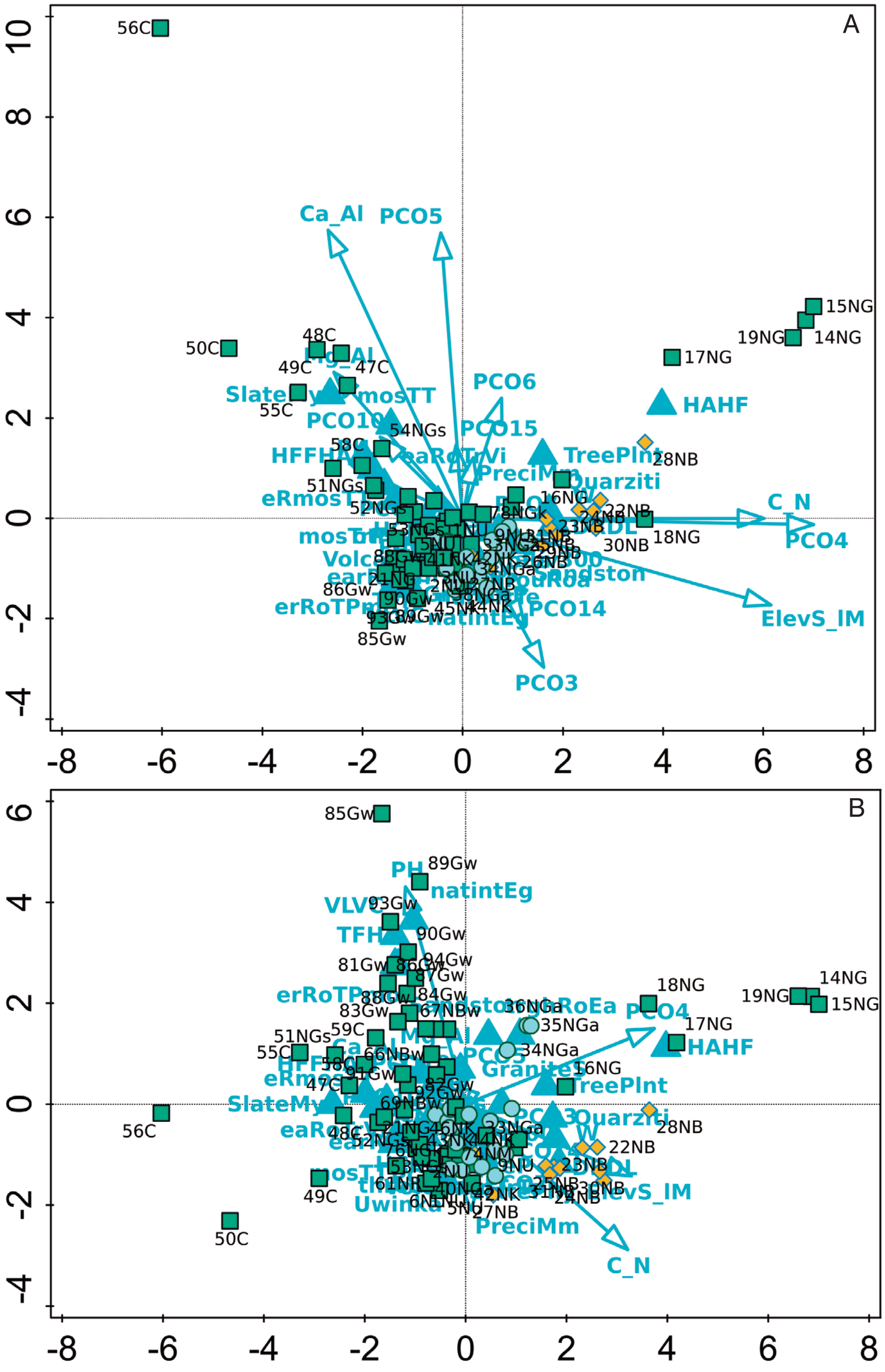


Figure 4.58 A-C: Biplot as a result of variation partitioning using CCA. The partitioning approach was done using three groups of explanatory variables. The first group consists of the environmental variables s. str. Based on a new forward selection considering the simple effects, the distance to the forest edge was also omitted in the current analysis, that tests for the conditional effects. The second group contains the soil parameters. The third group comprsises the spatial eigenfunctions. The global trend is still persent in the data analysed. Pane A of the current figure shows axis one and axis two. Pane B shows axes one and three. The resolution of the plots does not yield for reliable inferences. For interpretation, see the text.

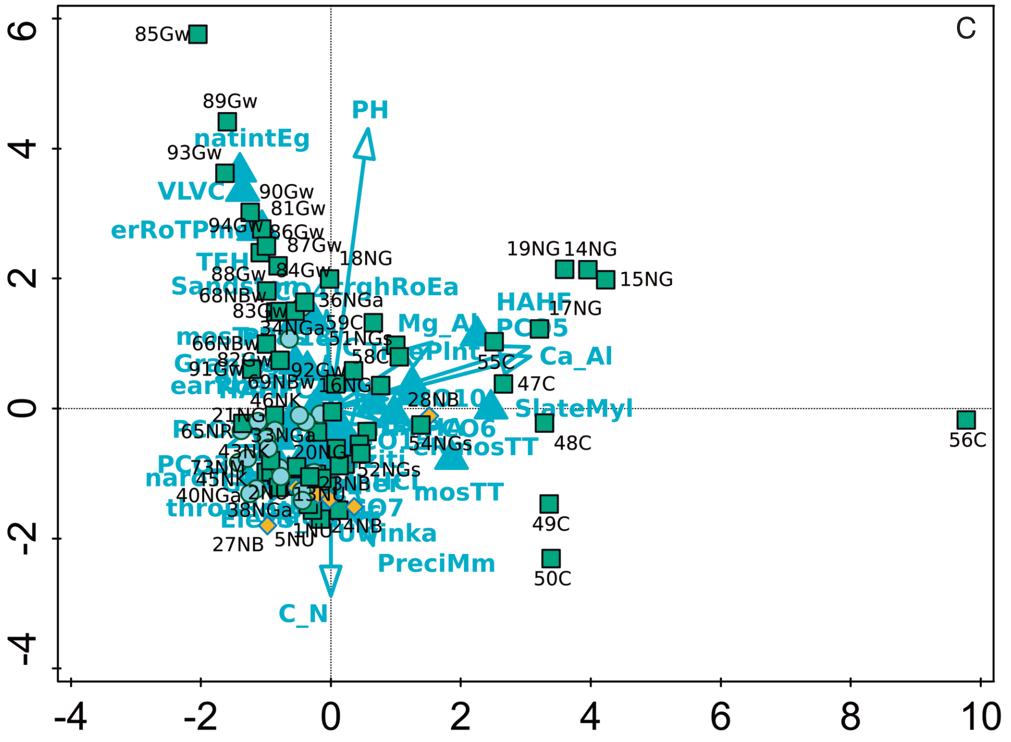


Figure 4.58 A-C: Biplot as a result of variation partitioning using CCA. The partitioning approach was done using three groups of explanatory variables. Pane C shows axes two and three. The resolution of the plots does not yield for reliable inferences. For interpretation, see the text.

4.2.5.3 Spatial Variation of the Environmental Variables

Now that it has been established that there is considerable overlap between spatial predictors and environmental variables, the question is raised as to which of the environmental variables are likely to be spatially structured and are correlated to the spatial predictors chosen. The question concerning at which spatial scale the supposed structure is manifested is posed as well.

To explain which environmental variables may exhibit a spatial structure, a dbMEM based analysis has been carried out with the environmental variables taking the role of the responses. Before, some of the analyses have been undertaken on detrended data, i.e., the global trend as found by trend surface analysis has been removed since it would have been modelled by the dbMEMs, as well. Some of the analyses, due to restrictions in the available software, have been conducted on the basis of un-detrended data. Setting up such an analysis would have only been possible in a laborious way presenting many pitfalls. Thus, in the following, both the un-detrended and detrended data have been used. The differences in results are given, if significant.

The spatial eigenfunctions computed before were used in this analysis. Since the functions rendered significant above were used to predict variation in species communities, they are not naturally of significance in the prediction of environmental variables (ver: Šmilauer & Lepš, 2014). During the dbMEM based analyses carried out, stepwise interactive forward selection was used to determine the spatial predictors having significant correlations with the environmental variables. The 95% confidence level has been chosen as a stopping criterion for further inclusion. When comparing the results with the dbMEMs carried out on the species variables, different spatial predictors have been picked, but the number of predictors in common suggests some similar variability. The spatial scales have been kept intact since the additional predictors chosen were all of a contiguous nature with the ones established prior. A comparison between Figures 4.57, 4.58 and 4.59, 4.60 should be taken with caution as the focus is on different response variables and thus the fit of different axes of variation has been optimised.

Since the approach based on CCA differs in that three of the samples had to be excluded from the model, the resulting differing sets of spatial predictors have been tested and evaluated separately by RDA. Starting with the spatial eigenfunctions stemming from the unimodal path, 18 of the 23 spatial variables computed were chosen during the interactive stepwise forward selection. Hence, some differences in the spatial structures of community variation and environmental variables are to be expected. Variation in the un-detrended environmental data could be explained through the spatial predictors to $48.16\%_{adj}$ (see Tab. 4.32). Removing the global trend still $43.77\%_{adj}$ (Tab. 4.33) of the variation could be explained by spatial predictors. Between both approaches the eigenvectors chosen remained unchanged.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.1133	0.0829	0.068	0.0576	0.0489
Explained variation (cumulative)	11.33	19.62	26.42	32.18	37.07
Pseudo-canonical correlation	0.943	0.9751	0.9601	0.9692	0.9411
Explained fitted variation (cumulative)	19.36	33.53	45.14	54.98	63.34

Table 4.32 a, b: Results of an RDA utilising the environmental variables s.l. as responses and the spatial eigenfunctions computed by dbMEM as independent variables. The set of spatial predictors stemms from a model based on CCA where three samples had to be omitted. The lower table shows the spatial predictors chosen by an interactive forward selection. The calculations are based on the un-detrended data. The total variation is 4004.00. The explanatory variables account for 58.53% or $48.16\%_{\text{adj}}$ of the variation in the responses. For interpretation, see the text.

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
PCO.1	7.1	11.6	6.8	0.001	0.00288
PCO.2	6.9	11.4	7.1	0.001	0.00288
PCO.3	6.3	10.3	6.9	0.001	0.00288
PCO.10	5.7	9.3	6.6	0.001	0.00288
PCO.5	4	6.5	4.8	0.001	0.0023
PCO.4	3.8	6.2	4.8	0.001	0.0023
PCO.11	3.6	5.8	4.7	0.001	0.00256
PCO.8	3.5	5.7	4.8	0.001	0.0023
PCO.12	2.4	3.9	3.4	0.001	0.00177
PCO.17	2.3	3.8	3.4	0.001	0.00177
PCO.7	2.3	3.7	3.4	0.001	0.00192
PCO.6	1.8	3	2.8	0.001	0.00177
PCO.16	1.7	2.8	2.7	0.004	0.00613
PCO.21	1.7	2.7	2.7	0.003	0.00493
PCO.9	1.6	2.7	2.7	0.002	0.00354
PCO.20	1.6	2.7	2.7	0.01	0.01438
PCO.14	1.2	2	2.1	0.034	0.04344
PCO.15	1.1	1.8	1.9	0.015	0.02029

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.1059	0.0658	0.0568	0.0386	0.0364
Explained variation (cumulative)	12.09	19.6	26.09	30.5	34.65
Pseudo-canonical correlation	0.9448	0.9709	0.9567	0.928	0.9353
Explained fitted variation (cumulative)	21.88	35.47	47.21	55.18	62.7

Table 4.33 a, b: The same data and procedure was used as before. The results shown stem from an approach using the detrended data. The partial variation is 3506.94. The explanatory variables account for 55.27% or $43.77\%_{\text{adj}}$ of the variation in the response data. See Annex 25 for VIFs.

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
PCO.3	8.1	13.8	7.6	0.001	0.00288
PCO.1	7	11.9	7	0.001	0.0023
PCO.2	4.6	7.8	4.8	0.001	0.00209
PCO.8	4.1	7	4.5	0.001	0.0023
PCO.11	3.9	6.6	4.5	0.001	0.00192
PCO.10	3.7	6.3	4.4	0.001	0.00209
PCO.4	3.5	6	4.4	0.001	0.00209
PCO.12	2.7	4.5	3.4	0.001	0.00177
PCO.17	2.5	4.2	3.2	0.001	0.00164
PCO.7	2.3	4	3.1	0.001	0.00177
PCO.6	2.1	3.5	2.9	0.001	0.00192
PCO.9	1.9	3.3	2.7	0.001	0.00192
PCO.21	1.8	3	2.5	0.005	0.00885
PCO.16	1.6	2.8	2.4	0.005	0.00821
PCO.14	1.5	2.5	2.2	0.006	0.0092
PCO.5	1.7	2.9	2.6	0.002	0.00354
PCO.20	1.3	2.3	2	0.025	0.03026
PCO.15	1.2	2	1.8	0.021	0.02841

Up until PCO.12, all scales of spatial variation were chosen, with the first three followed by PCO.10 accounting for most of the variation. While, in total, the pattern remains the same, the amount of variation explained by the respective predictors changed marginally in the approach based on the detrended data.

Šmilauer & Lepš (2014, p. 233 f) stated that the interpretation of individual eigenfunctions should proceed with care, not least in cases where contiguous groups have been chosen. The advice given in Borcard et al. (2018) to use the subsets of spatial predictors in separate constrained analyses according to the scale they represent has been followed. Since the spatial predictors are independent of each other, overlap between the partial models does not occur.

Keeping the broad-scale spatial predictors known to have an impact on community composition in the analysis results in 19.85%$_{adj}$ explained variation. What can be seen from the graphs is that PCO.1 and PCO.3 are correlated most with axis one and axis two, respectively. The PCO.1 predictor sets apart the Uwinka visitor centre and the slate/phyllonite geology as well as the through road. Another conspicuous relation exists between pH-value and PCO.1. Not as conspicuous, but in keeping with prior knowledge, precipitation displays a spatial structure related to PCO.1 as well. At the broad scale, PCO.3, PCO.4 and PCO.6 are related to elevation a.s.l. and the distance from the forest margin. In conjunction with PCO.1 all three of the above predictors are related to the [C]:[N] ratio and the separation of the samples from the Nile side, the Congo side and the watershed. A plot of axes one and four shows that the buffer zones consisting of tree plantations seem to introduce some spatial structure as well. The separation of the Nile and Congo sides can be seen along PCO.5 and PCO.7, both of which are correlated with the [Mg]:[Al] and [Ca]:[Al] ratios as well. A relation of said ratios can also be inferred to PCO.3 and, thus, to the elevation and [C]:[N] ratio. Analysis of the detrended data brought about no decisive change. Some of the spatial predictors changed in importance along some of the axes; however, the relations between spatial predictors and environmental variables remained unchanged (see Tables 4.34 & 4.35).

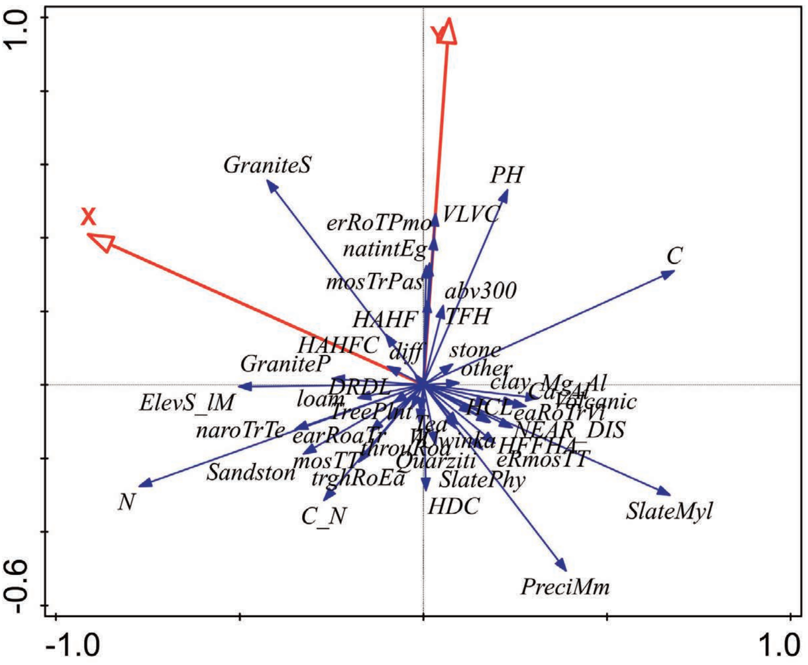
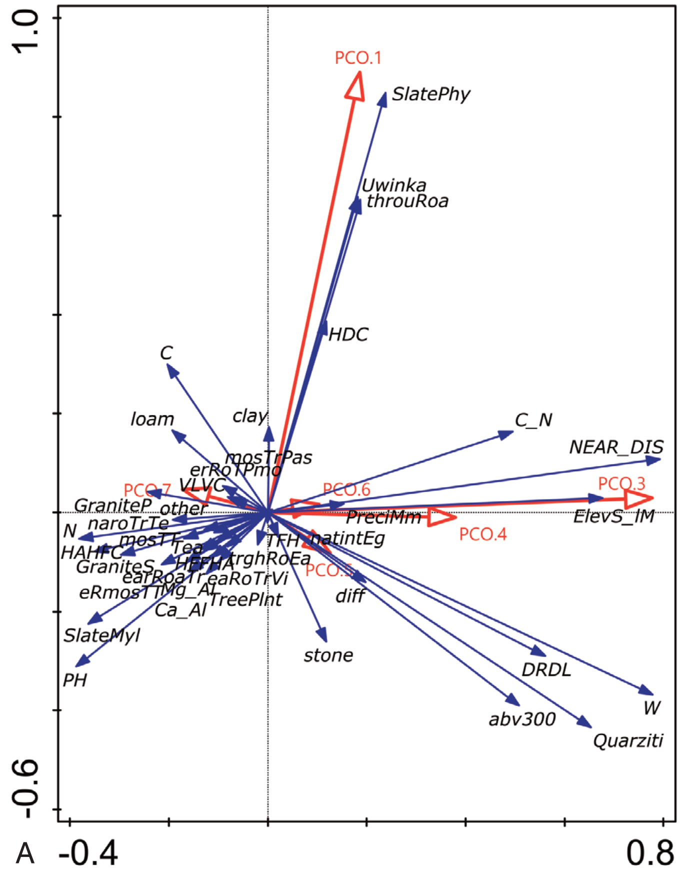


Figure 4.59: Biplot as a result of an RDA. To illustrate the global trend in the environmental variables s.l., the XY coordinates have been employed as explanatory variables. The bearing relations between the vectors can be used to give a rough indication of the spatial patterns in the environmental parameters.



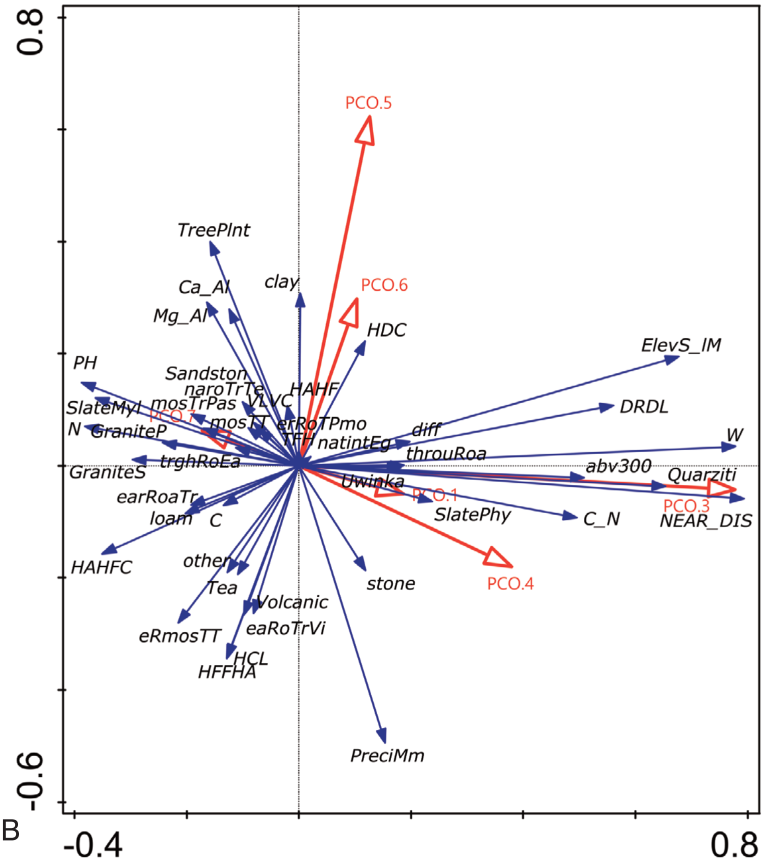
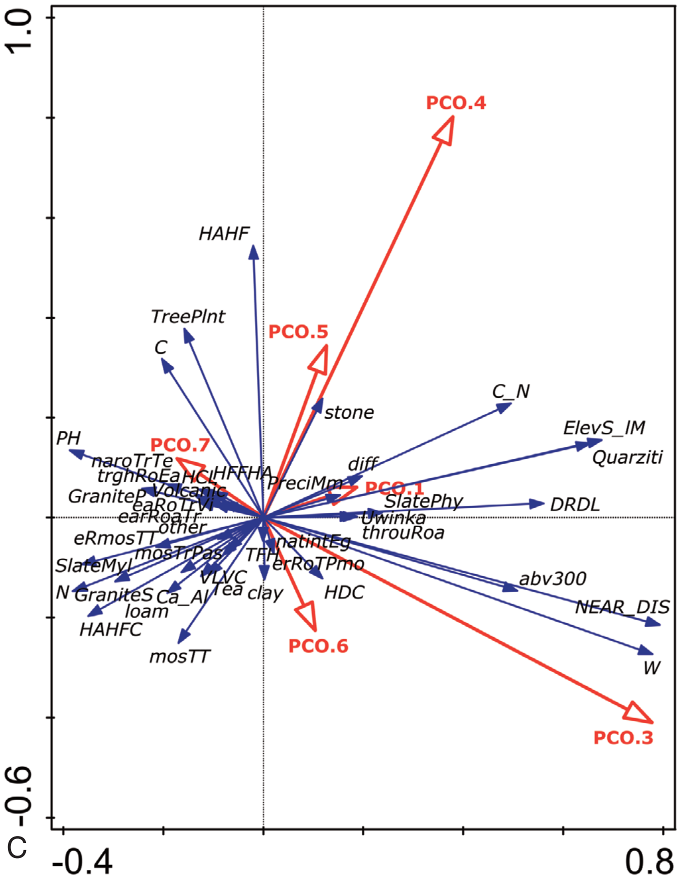
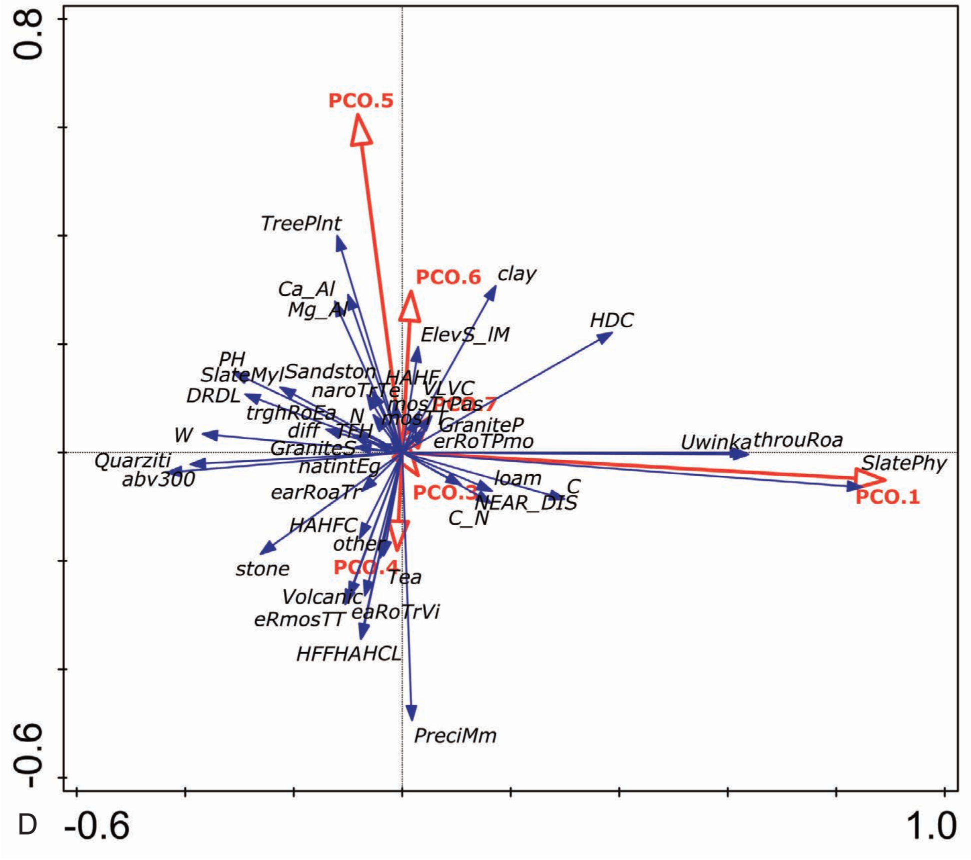


Figure 4.60 A-D: Biplots as a result of an RDA. The data stem from an approach where three samples had to be omittred. The bearing relations between the vectors can be used to infer changes in the environmental parameters s.l. in correlation to the geographical space. The spatial predictors illustrated are deemed to represent changes on a broad spatial scale. Pane A depicts axes one and two, pane B axes one and three, pane C axes one and four and pane D depicts axes two and three.

Figure 4.60 A-D: Biplots as a result of an RDA. The data stem from an approach where three samples had to be omittred. The bearing relations between the vectors can be used to infer changes in the environmental parameters s.l. in correlation to the geographical space. The spatial predictors illustrated are deemed to represent changes on a broad spatial scale. Pane A depicts axes one and two, pane B axes one and three, pane C axes one and four and pane D depicts axes two and three.





Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.0825	0.067	0.0437	0.0261	0.0185
Explained variation (cumulative)	8.25	14.95	19.32	21.94	23.78
Pseudo-canonical correlation	0.8762	0.9475	0.8155	0.8037	0.6838
Explained fitted variation (cumulative)	32.74	59.34	76.69	87.06	94.39

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
PCO.1	7.1	11.6	6.8	0.001	0.00288
PCO.3	6.3	10.3	6.4	0.001	0.00288
PCO.4	3.8	6.2	4	0.001	0.00288
PCO.5	4	6.5	4.3	0.001	0.00288
PCO.7	2.3	3.7	2.5	0.005	0.0115
PCO.6	1.8	3	2.1	0.003	0.0069

Table 4.34 a, b: Results of an RDA utilising the environmental variables s.l. as responses and the spatial eigenfunctions computed by dbMEM as independent variables. The set of spatial predictors used are intended to represent the broad spatial scale of variation in the environmental variables s.l. The data stem from a model based on CCA where three samples had to be omitted. The calculations are based on the un-detrended data. The total variation is 4004.00. The explanatory variables account for 25.02% or 19.85%$_{adj}$ of the variation in the responses. For interpretation, see the text.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.0966	0.0633	0.0337	0.0262	0.0179
Explained variation (cumulative)	11.02	18.25	22.1	25.09	27.14
Pseudo-canonical correlation	0.9089	0.9554	0.8587	0.8126	0.7027
Explained fitted variation (cumulative)	38.18	63.23	76.56	86.92	94.01

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
PCO.3	8.1	13.8	7.6	0.001	0.00288
PCO.1	7	11.9	7	0.001	0.0023
PCO.4	4.6	7.8	4.8	0.001	0.0023
PCO.5	3.6	6.2	4	0.001	0.00209
PCO.7	3.4	5.9	3.9	0.001	0.00192
PCO.6	2.2	3.8	2.6	0.001	0.00192

Table 4.35 a, b: Same as approach as before. Here, the calculations are based on the detrended data. The partial variation is 3506.94. The explanatory variables account for 28.87% or 23.67%$_{adj}$ of the variation in the responses. See Annex 26 for VIFs. For interpretation, see the text.

The predictors depicting the medium scale, PCO.8 & PCO.10, seem to be mostly correlated with forest matrix states, soil types and geology. The PCO.10 predictor shows some correlation to mean annual precipitation as well and seems to have some negative correlation to elevation. The variation in the environmental variables explained by the medium scale spatial predictors amounts to 7.11%$_{adj}$ (Tabs. 4.36 & 4.37). Graph 4.61 details the relations.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.057	0.0347	0.126	0.0755	0.0715
Explained variation (cumulative)	5.7	9.17	21.77	29.33	36.48
Pseudo-canonical correlation	0.8594	0.8258	0	0	0
Explained fitted variation (cumulative)	62.21	100			

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
PCO.8	4.3	7.4	3.9	0.001	0.00288
PCO.10	3.9	6.6	3.6	0.001	0.00288

Table 4.36 a, b: Same as approach as before. Here, the calculations are based on the un-detrended data. The total variation is 4004.00. The explanatory variables account for 9.17% or 7.11%$_{adj}$ of the variation in the responses. The predictors represent the medium-scale.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.0379	0.034	0.1191	0.0706	0.0569
Explained variation (cumulative)	4.32	8.2	21.8	29.86	36.36
Pseudo-canonical correlation	0.8283	0.8948	0	0	0
Explained fitted variation (cumulative)	52.7	100			

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
PCO.8	4.3	7.4	3.9	0.001	0.00288
PCO.10	3.9	6.6	3.6	0.001	0.00288

Table 4.37 a, b: Same as approach as before. Here, the calculations are based on the detrended data. The partial variation is 3506.94. The explanatory variables account for 8.20% or 6.07%$_{adj}$ of the variation in the responses. The predictors represent the medium-scale. See Annex 27 for VIFs.

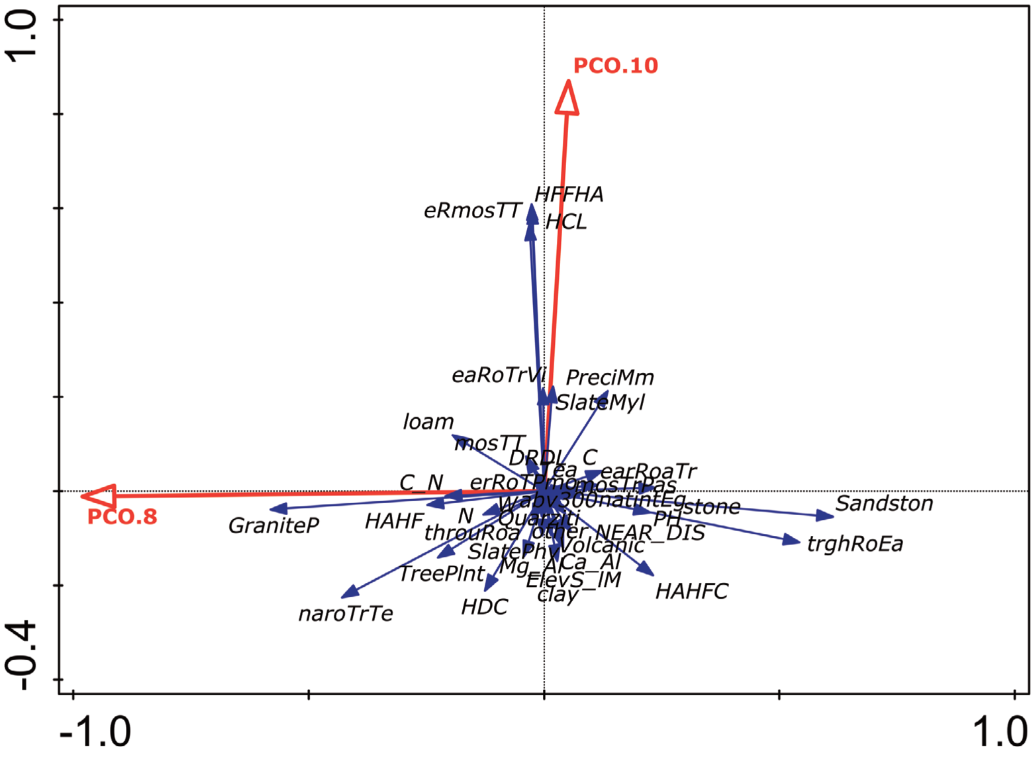


Figure 4.61: Biplots as a result of an RDA. The data stem from an approach where three samples had to be omittred. The bearing relations between the vectors can be used to infer changes in the environmental parameters s.l. in correlation to the geographical space. The spatial predictors illustrated are intended to represent changes on a medium spatial scale. The data were detrended prior to the analysis. Axes one and two are depicted.

Some of the medium scale spatial predictors (PCO.14 to PCO.17) lost their significance in the respective submodel. It stands to reason that these already model vegetation patterns not solely due to independent variables but to neutral proccesses. These however, occur within the single forests and therefore do not model substantial variations among forests. An indication to strenghten this asumption is given by the direction of the isolines in the graps of Fig. 4.54. The vectors representing the change in the east-west direction shown in the figures have only a low correlation to the ordination axes.

Like in the example given in BORCARD ET AL. (2018), the fine-scaled model is not significant. The authors stated that these fine-scale structures are often related to dynamic community processes (IBID.).

When establishing the relations between the spatial predictors stemming from the linear model and the environmental variables, 18 of the 24 spatial predictors computed were chosen during interactive stepwise forward selection. In the model within which the global trend had been removed prior to forward selection, 16 spatial predictors were left in the analysis. In the analyses, $47.06\%_{adj}$ and $41.25\%_{adj}$ (Tabs. 4.38 & 4.39) of the variation in the environmental data was explained, respectively. Within the detrended model, PCO.2 and PCO.15 were left out during forward selection. In the first case, it may be concluded by inference that the global trend had been modelled to a larger extent by this variable.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.1124	0.0807	0.0651	0.0551	0.0474
Explained variation (cumulative)	11.24	19.31	25.82	31.32	36.06
Pseudo-canonical correlation	0.9414	0.9739	0.9567	0.9654	0.9394
Explained fitted variation (cumulative)	19.61	33.7	45.05	54.66	62.93

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
PCO.3	8.2	13.6	8.3	0.001	0.00343
PCO.1	6.8	11.3	7.3	0.001	0.003
PCO.2	5.6	9.3	6.3	0.001	0.003
PCO.10	5.4	9	6.5	0.001	0.003
PCO.5	3.9	6.4	4.8	0.001	0.00267
PCO.4	3.7	6.1	4.8	0.001	0.00267
PCO.8	3.4	5.6	4.6	0.001	0.0024
PCO.11	2.7	4.5	3.9	0.001	0.002
PCO.13	2.3	3.9	3.4	0.001	0.002
PCO.17	2.2	3.7	3.3	0.002	0.00369
PCO.7	2.1	3.5	3.3	0.001	0.002
PCO.12	1.8	3	2.9	0.001	0.002
PCO.6	1.7	2.8	2.7	0.001	0.002
PCO.21	1.6	2.7	2.6	0.005	0.008
PCO.16	1.6	2.7	2.7	0.012	0.018
PCO.9	1.6	2.6	2.7	0.002	0.00343
PCO.20	1.6	2.6	2.7	0.035	0.04933
PCO.15	1	1.6	1.7	0.031	0.04376

Table 4.38 a, b: Results of an RDA using the spatial predictors calculated by dbMEM based on all sample plots. The environmental parameters s.l. were used in the response role. The calculations are based on the un-detrended data. The total variation is 4230.00. The explanatory variables account for 57.31% or $47.06\%_{adj}$ of the variation in the responses.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.1032	0.0647	0.0539	0.0413	0.0367
Explained variation (cumulative)	11.73	19.09	25.22	29.92	34.09
Pseudo-canonical correlation	0.937	0.9659	0.9496	0.9192	0.9152
Explained fitted variation (cumulative)	22.74	37.01	48.89	58	66.09

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
PCO.3	9.6	16.6	9.5	0.001	0.003
PCO.1	7	12.1	7.5	0.001	0.003
PCO.10	4.1	7.2	4.6	0.001	0.00267
PCO.8	4.1	7.1	4.8	0.001	0.00267
PCO.4	3.6	6.3	4.4	0.001	0.00218
PCO.5	4	6.8	5	0.001	0.0024
PCO.7	2.7	4.7	3.6	0.001	0.0024
PCO.9	2	3.5	2.7	0.001	0.00218
PCO.13	2	3.4	2.6	0.004	0.00873
PCO.11	1.9	3.3	2.6	0.002	0.00436
PCO.12	1.9	3.3	2.7	0.003	0.00655
PCO.21	1.9	3.2	2.7	0.008	0.01371
PCO.17	1.8	3.2	2.7	0.005	0.00923
PCO.6	1.7	3	2.6	0.001	0.00267
PCO.16	1.5	2.6	2.3	0.016	0.024
PCO.20	1.6	2.8	2.5	0.026	0.03671

Table 4.39 a, b: The same approach as before. Here, the calculations are based on the detrended data. The partial variation is 3720.53. The explanatory variables account for 51.58% or 41.25%$_{adj}$ of the variation in the responses. See Annex 28 for VIFs.

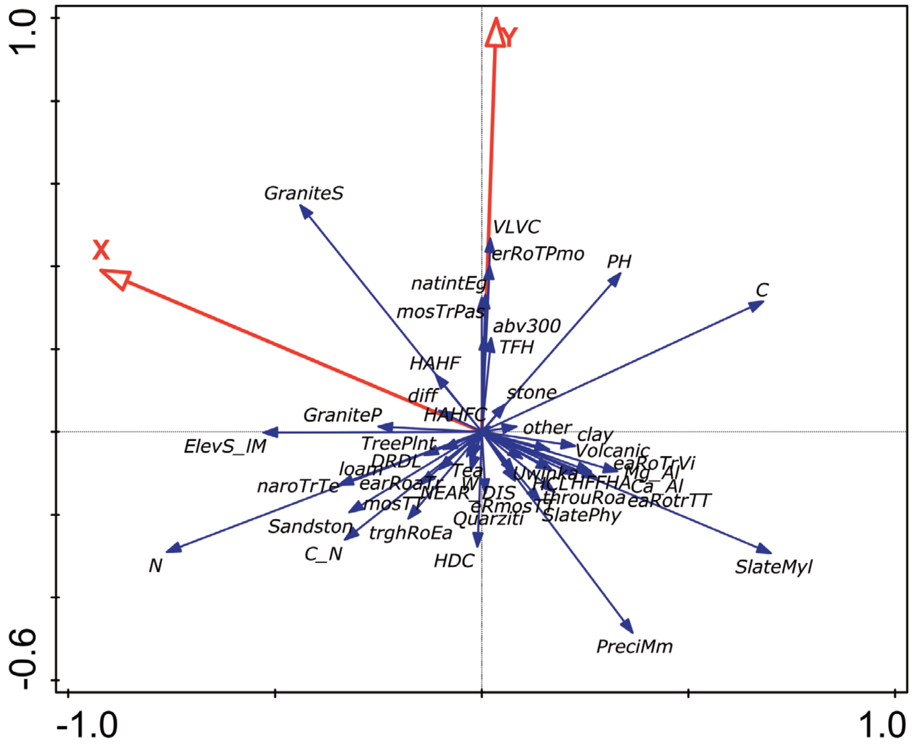


Figure 4.62: Biplot as a result of an RDA. The global trend within the environmental variables s.l. is illustrated using the XY coordinates as explanatory variables. The relations between the vectors are indicative of the spatial patterns of the environmental parameters.

On the coarse scale, PCO.1 and PCO.3 again can be used to explain the largest part of the variation. Albeit with changed signs, very much the same relations can be inferred from this approach as from the model based on the unimodal concept. Elevation, the distance to the forest margin, the [C]:[N] ratio and precipitation seem to be negatively correlated to PCO.3, while the [C]:[N] ratio and the distance to the forest margin show some relation to PCO.1 as well. The samples from Uwinka are again separated along PCO.1. Axes two and three can be used to separate the Nile and Congo side as well as the samples from the watershed. The ratios [Ca]:[Al] and [Mg]:[Al] seem to be negatively correlated to PCO.4 along axis three. For the coarse scale, 19.09%$_{\text{adj}}$ of the variation could be explained, including the global trend, while 20.91%$_{\text{adj}}$ of the variation in the environmental data could be attributed to spatial structures based on the detrended data. Correlations between explanatory and response variables remained unchanged (see Tables 4.40 & 4.41; Figure 4.63).

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.0897	0.0654	0.046	0.0247	0.0805
Explained variation (cumulative)	8.97	15.51	20.11	22.57	30.62
Pseudo-canonical correlation	0.8706	0.9497	0.8388	0.8038	0
Explained fitted variation (cumulative)	39.73	68.7	89.07	100	

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
PCO.3	8.2	13.6	8.3	0.001	0.00343
PCO.1	6.8	11.3	7.3	0.001	0.003
PCO.4	3.7	6.1	4.1	0.001	0.00267
PCO.5	3.9	6.4	4.4	0.001	0.003

Table 4.40 a, b: Results of an RDA using the broad-scale spatial predictors calculated by dbMEM based on all sample plots. The environmental parameters s.l. were used in the response role. The calculations are based on the un-detrended data. The total variation is 4230.00. The explanatory variables account for 22.57% or 19.09%$_{\text{adj}}$ of the variation in the responses.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.092	0.06	0.038	0.0246	0.0592
Explained variation (cumulative)	10.46	17.27	21.59	24.39	31.12
Pseudo-canonical correlation	0.8942	0.9451	0.8585	0.8167	0
Explained fitted variation (cumulative)	42.88	70.83	88.55	100	

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
PCO.3	9.6	16.6	9.5	0.001	0.003
PCO.1	7	12.1	7.5	0.001	0.00267
PCO.5	3.8	6.6	4.2	0.001	0.003
PCO.4	4	6.9	4.6	0.001	0.00267

Table 4.41 a, b: The same approach as before. Here, the calculations are based on the detrended data. The partial variation is 3720.53. The explanatory variables account for 24.39% or 20.91%$_{\text{adj}}$ of the variation in the responses. See Annex 29 for VIFs.

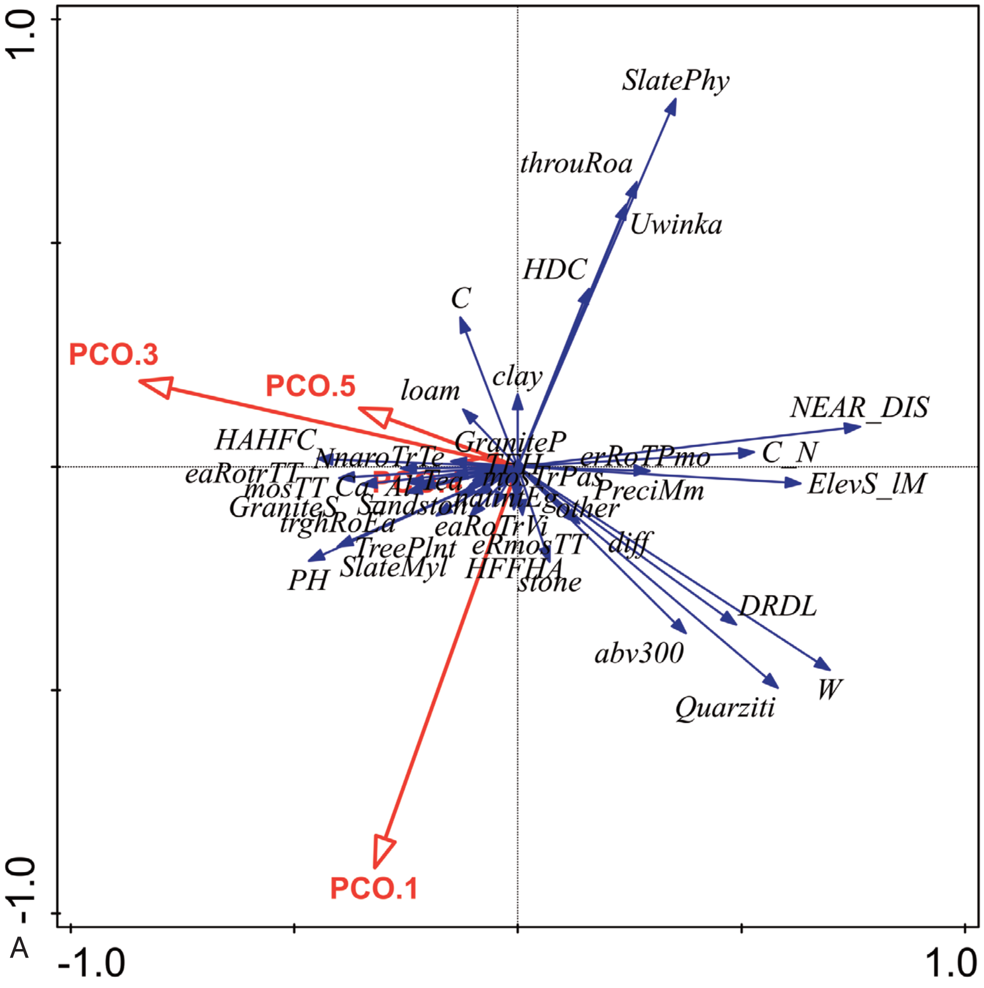


Figure 4.63 A - C: Biplots as a result of an RDA. The data stem from an approach including all samples. The bearing relations between the vectors can be used to infer changes in the environmental parameters s.l. in correlation to the geographical space. The spatial predictors illustrated are intended to represent changes on a broad spatial scale. The data were detrended prior to the analysis. Axes one and two are schown in pane A. Axes one and three are depicted in pane B and axes two and three in pane C.

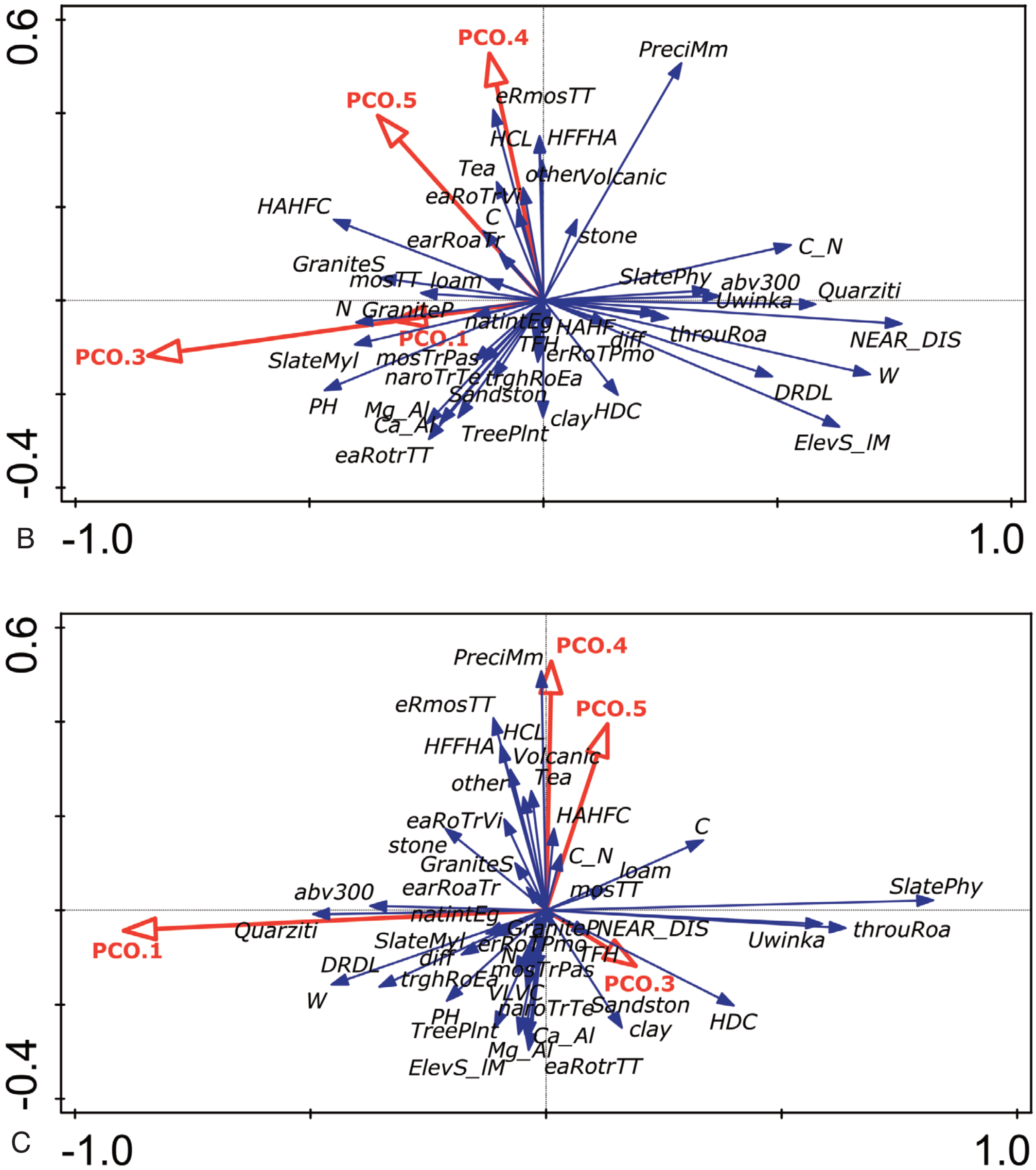


Figure 4.63 A - C: Biplots as a result of an RDA. The data stem from an approach including all samples. The bearing relations between the vectors can be used to infer changes in the environmental parameters s.l. in correlation to the geographical space. The spatial predictors illustrated are intended to represent changes on a broad spatial scale. The data were detrended prior to the analysis. Axes one and three are depicted in pane B and axes two and three in pane C.

At the medium scale, spatial predictors account for 6.06%$_{adj}$ in the un-detrended and 7.29%$_{adj}$ in the detrended model. Here, as in the unimodal model, variations in soil type, geology, forest matrix and precipitation exhibit a spatial structure. Moreover, with regard to the fine-scaled variation, non-significant results were also obtained (see Tables 4.42 & 4.43; Figure 4.64).

With that, the overlaps between the spatial and environmental fractions have been attributed to specific environmental factors. The overlap established that the environmental factors s.l. mentioned above are spatially structured. When interpreting the results of the variation partioning approaches, it must be kept in mind that these common fractions only express a correlation between explanantory variables in the different groups (Borcard et al., 2018).

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.0416	0.0314	0.0182	0.0097	0.1275
Explained variation (cumulative)	4.16	7.31	9.13	10.1	22.85
Pseudo-canonical correlation	0.8107	0.8077	0.6667	0.5212	0
Explained fitted variation (cumulative)	41.22	72.35	90.35	100	

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
PCO.7	2.1	3.5	2	0.013	0.0312
PCO.8	3.4	5.6	3.3	0.001	0.003
PCO.11	2.7	4.5	2.7	0.002	0.006
PCO.12	1.8	3	1.8	0.021	0.04582

Table 4.42 a, b: Results of an RDA using the medium-scale spatial predictors calculated by dbMEM based on all sample plots. The environmental parameters s.l. were used in the response role. The calculations are based on the un-detrended data. The total variation is 4230.00. The explanatory variables account for 10.10% or 6.06%$_{adj}$ of the variation in the responses.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5
Eigenvalues	0.0396	0.0321	0.0188	0.0095	0.1164
Explained variation (cumulative)	4.51	8.15	10.29	11.37	24.6
Pseudo-canonical correlation	0.8406	0.8082	0.6384	0.5376	0
Explained fitted variation (cumulative)	39.65	71.72	90.52	100	

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
PCO.8	4.1	7.2	3.9	0.001	0.003
PCO.7	2.2	3.9	2.1	0.008	0.02133
PCO.12	2.1	3.6	2	0.021	0.042
PCO.11	2.9	5	2.8	0.001	0.003

Table 4.43 a, b: The same approach as before. Here, the calculations are based on the detrended data. The partial variation is 3720.53. The explanatory variables account for 11.37% or 7.29%$_{adj}$ of the variation in the responses. See Annex 30 for VIFs.

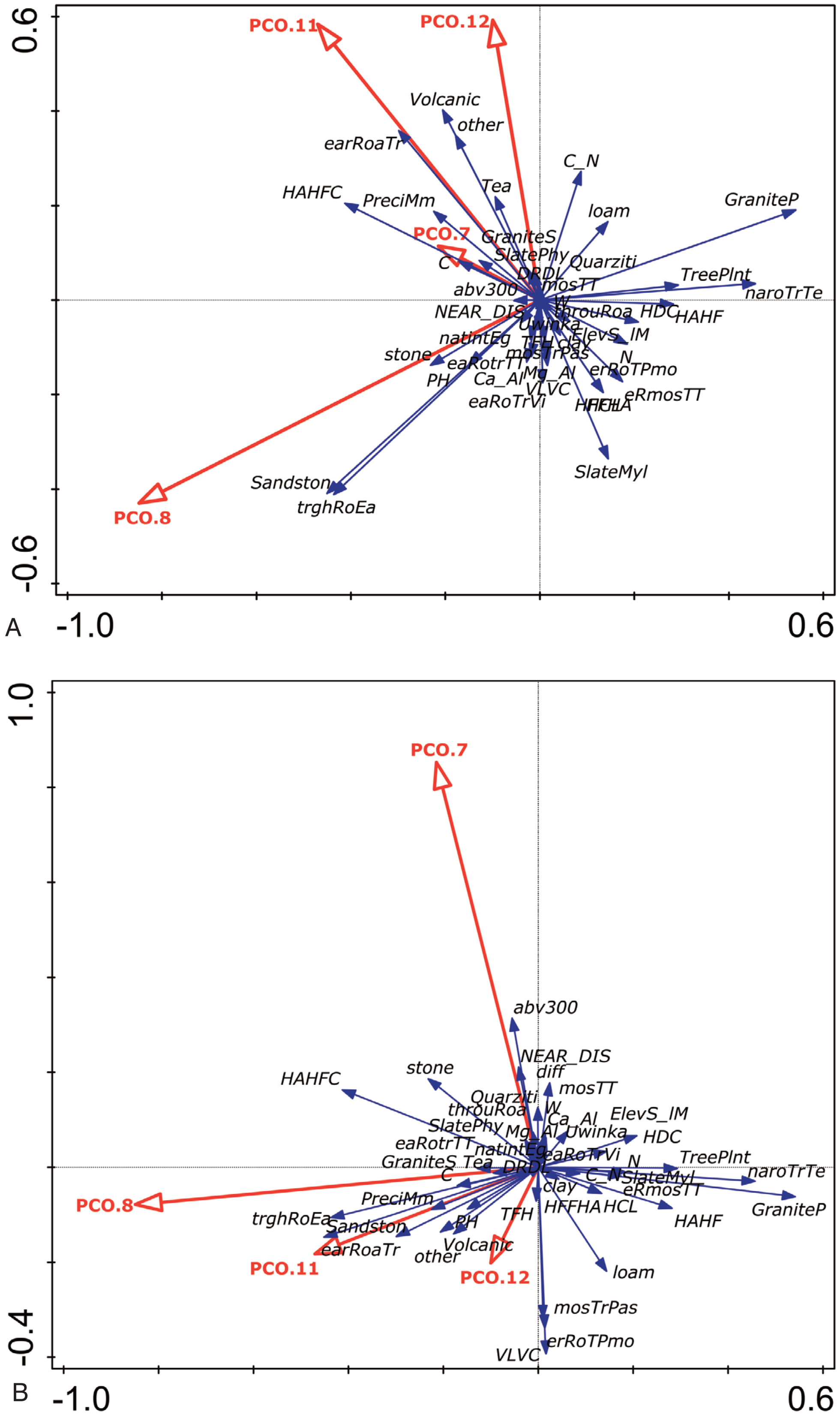


Figure 4.64 A - C: Biplots as a result of an RDA. The data stem from an approach including all samples. The spatial predictors illustrated are intended to represent changes on a medium spatial scale. The data were detrended prior to the analysis. In pane A axes one and two are shown. Axes one and three are depicted in pane B and axes two and three in pane C.

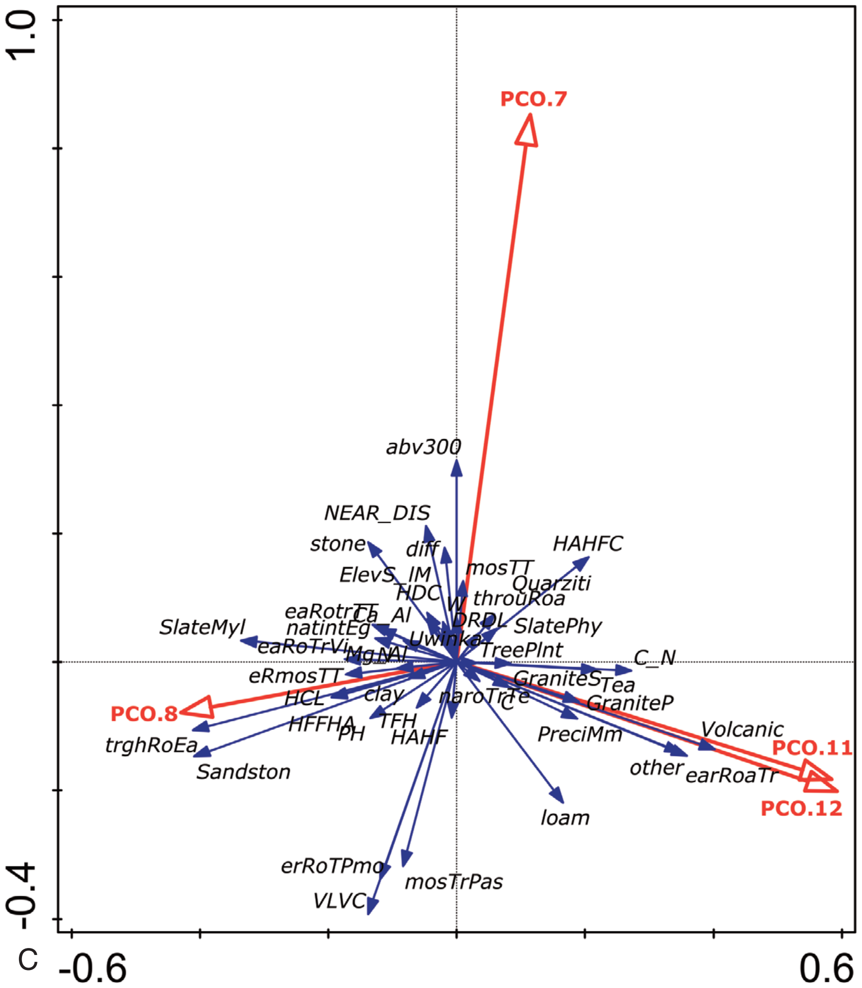


Figure 4.64 A - C: Biplots as a result of an RDA. The data stem from an approach including all samples. The bearing relations between the vectors can be used to infer changes in the environmental parameters s.l. in correlation to the geographical space. The spatial predictors illustrated are intended to represent changes on a medium spatial scale. The data were detrended prior to the analysis. Axes one and three are depicted in pane B and axes two and three in pane C.

For both approaches several spatial predictors have been chosen additionally to or instead of the ones of significance in the analyses of variation in the vegetation. On comparison, the respective spatial predictors each model patterns very similar to the ones chosen in the vegetation model. Most of the spatial predictors chosen in the environmental model but not in the vegetation model are not well correlated with the ordination axes. So, either the PCO.n depict spatial variation in the environmental variables which is not expressed by a variation in the vegetation or the effect is not substantial. This might be the case for two reasons; one because it is not of any impact, two the sampling design failed to pick up the compositional differences in the vegetation. Considering the similarity between the patterns modelled by the spatial predictors, a third reason could be given. Since forward selection was used during the partial approaches, the variation delineated by the spatial predictors chosen only in the environmental model may have been already expressed and therefore superimposed and / or integrated by the predictors chosen before them. The above-mentioned similarities in the variation patterns may have led to this phenomenon (e.g., PCO.18 and PCO.20 in Figs. 4.56 K & L). Clearly though there is a correlation between the spatial predictors and the environmental factors. The intersecting set of significant spatial predictors from the vegetation and the environmental model therefore allow for the inference of spatially structured environmental factors which in turn impact vegetation composition.

In summary in both settings the broad scale spatial predictors are correlated to elevation a.s.l., the distance to the forest edge, [C]:[N], the Uwinka ranger station and the road running through Nyungwe as well as the geology found there. The mean annual precipitation, soil pH, the positions towards the watershed, further forest matrix states and the ratios of [Al] to [Ca] and [Mg] are also correlated with the broad scale spatial predictors.
The medium scale still offers some correlation to mean annual precipitation and [C]:[N]. The largest correlations can be found to forest matrix states featuring roads and to geology.

Given the state of the analyses and the available sample material, it can be stated that, the correlations of the fine scale spatial predictors to the vegetation data seem to be result of community dynamics.

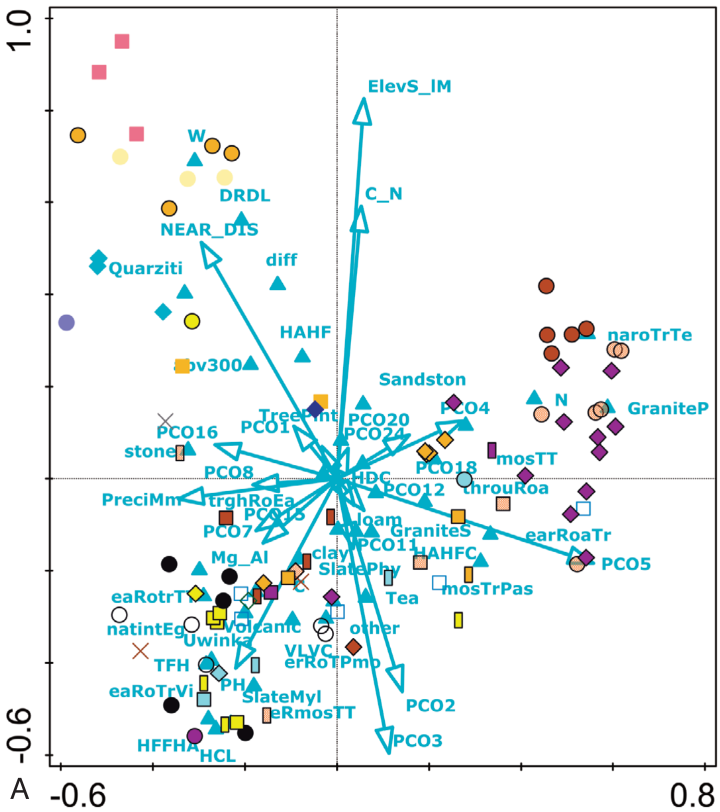
4.2.5.4 Representation of the Plant Communities in the Ordinations

Yet another question should be answered. How is the structure of the communities developed during the classification procedure recovered be the ordination procedures?

Utilising the final variation partitioning approach, the communities described under 3.2 have been moderately well recovered by RDA. Of all the communities, the Macarango psychotrietum shows the wides dispersion across the ordination space. The *Xymalos monospora*-*Symphonia globulifera*-*Myrinathus holsti* community is likewise spread out but mainly along the first axis, and the same is true for the *Symphonia globulifera*-*Strombosia scheffleri*-*Measa lanceolata* community. One sample, 79NGk, is separated from the *Syzygium parvifolium – Macaranga kilimandscharica* community along axis one. With some increased dispersion along axis two, the *Macaranga* dominated secondary forest is well depicted along axis one.

With CCA, recovery of the community structure did not succeed as well. During the variation partitioning process, what looks like a severe arch effect has been reintroduced, rendering the interpretation of the graph questionable, albeit the retrieval of the species communities established was not completely unsuccessful.

Figure 4.65: The symbols used to depict the plant communities developed under 3.2.



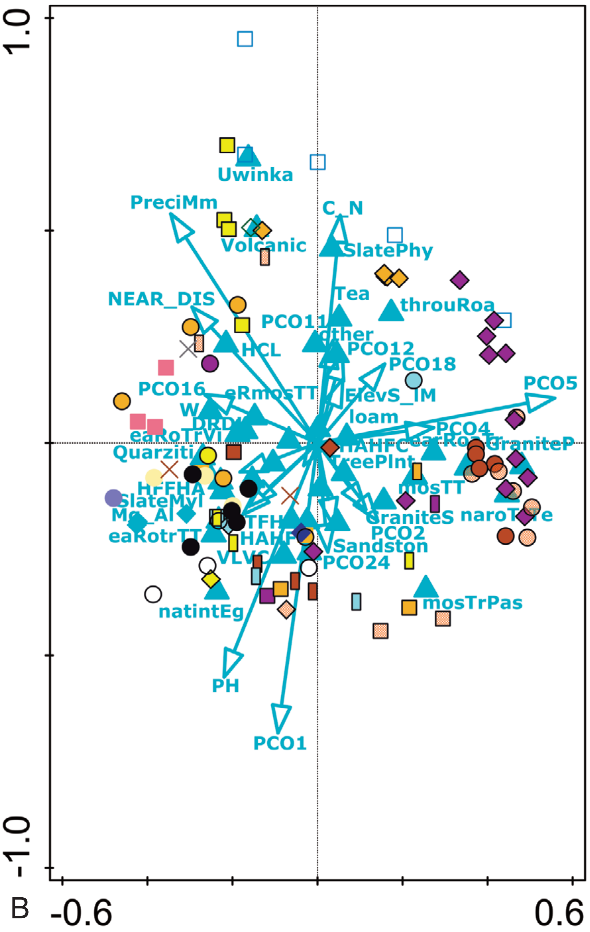


Figure 4.65 A - C: The plant communities developed under 3.2 are depicted in the biplots stemming from the variation partitioning approach with three groups. Here, tb-RDA was used. Pane A illustrates the separation of the communities along axes one and two. Pane B shows axes one and three, and pane C axes two and three. The legend is given on page 338.

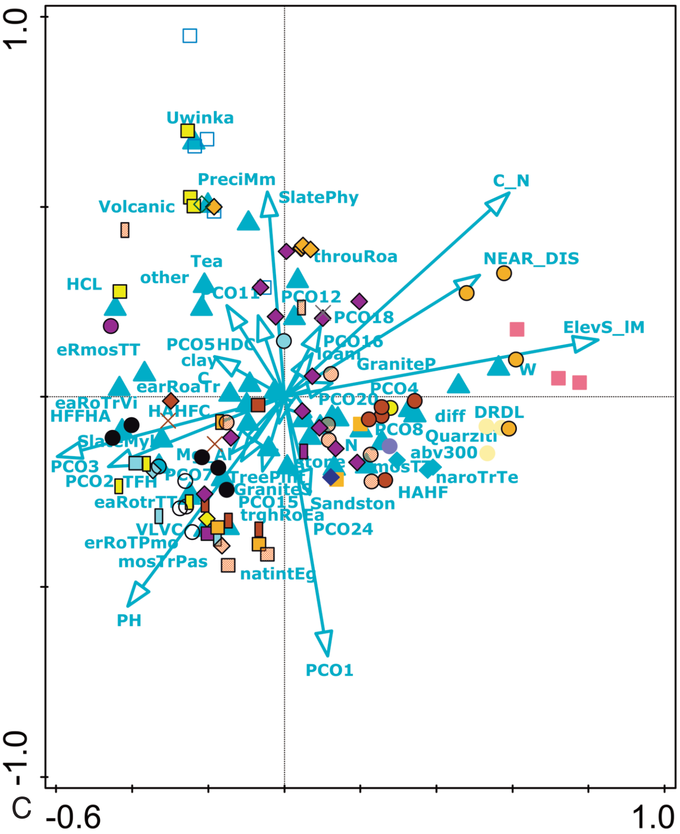


Figure 4.65 C: Axes two and three are shown. The legend is given on page 338.

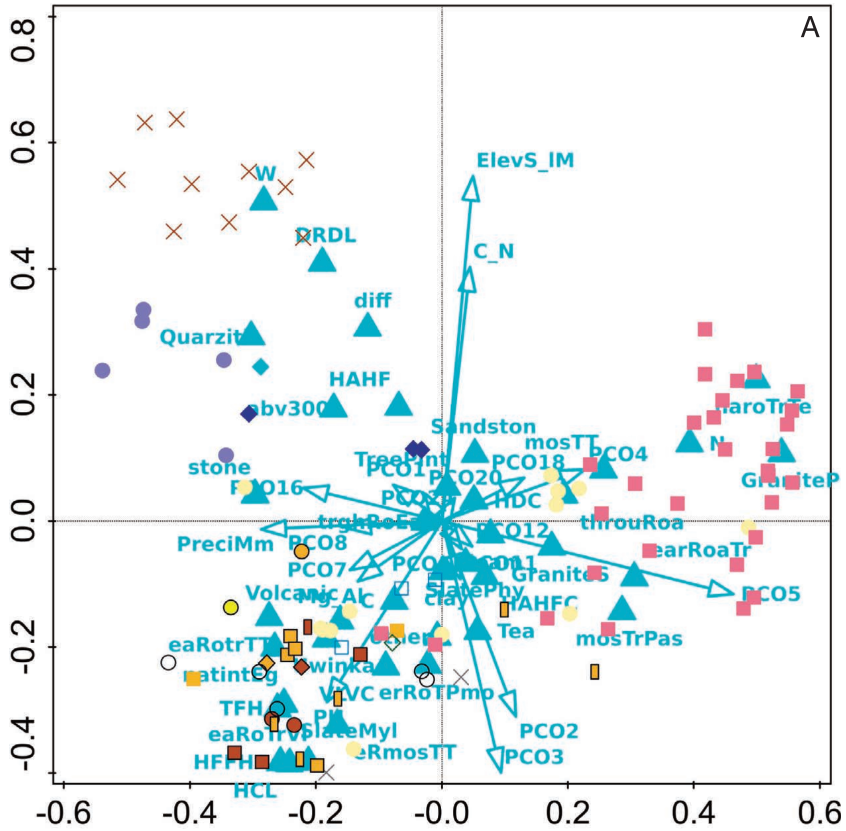


Figure 4.66 A: The plant supra-communities developed under 3.2 are depicted. The biplot stems from a variation partitioning approach with three groups based on tb-RDA Pane A shows axes one and two.

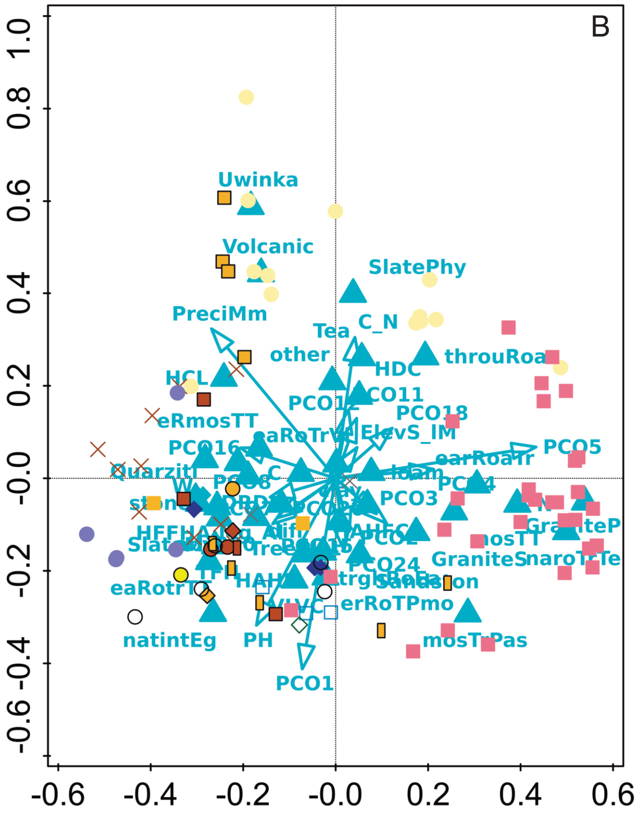


Figure 4.66 A - C: The plant supra-communities developed under 3.2 are depicted in the biplots stemming from the variation partitioning approach with three groups. Here, tb-RDA was used. Pane A illustrates the separation of the supra-communities along axes one and two. Pane B shows axes one and three, and pane C axes two and three. The legend is given on below.

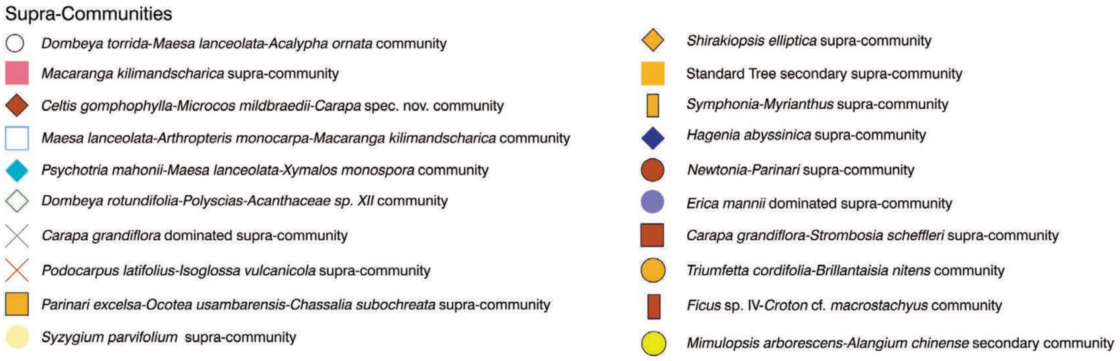


Figure 4.66: The symbols used to depict the supra-communities developed under 3.2.

The representation of the developed supra-communities is somewhat better, at this point the results obtained via the RDA are also more convincing (Fig. 4.66). The resolution of the samples and thus of the different communities in the ordination space defined by the CCA hardly allows for an interpretation. The graphs of the first and third axes and of the second and third axes are most useful for depicting the community structures, but they also allow interpretation only to a limited extent (Fig. 4.68). The ordination based on db-RDA provided a moderate depiction of the classified samples as well. At least along the first and second axes, plant communities could be distinguished. Recovery of the supra-communities along the first and second axes is barely acceptable (graphs not shown).

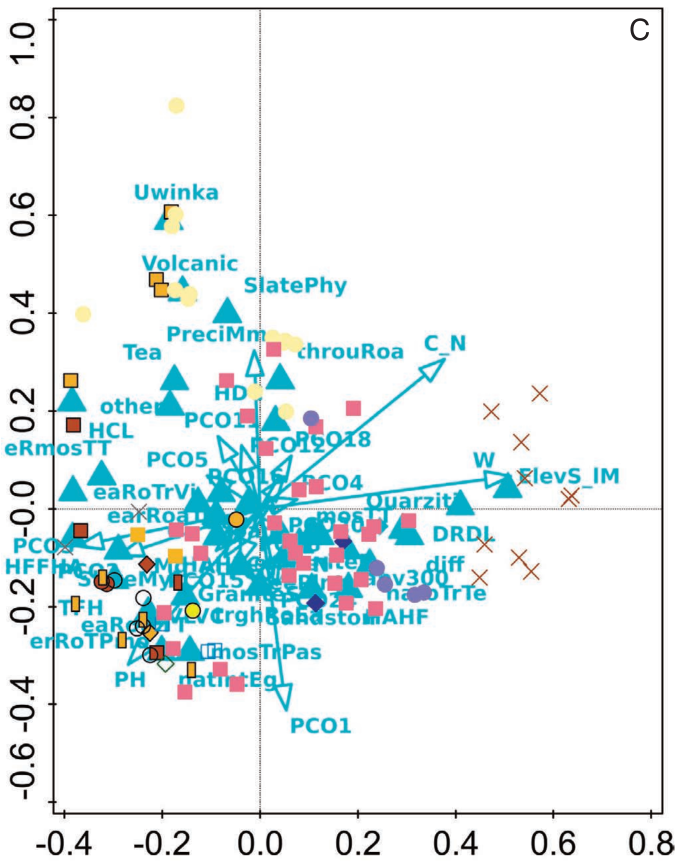


Figure 4.66 C: The plant supra-communities developed under 3.2 are depicted. The biplot stems from a variation partitioning approach with three groups based on tb-RDA Pane C shows axes two and three.

Communities

- ○ *Dombeya torrida-Maesa lanceolata-Acalypha ornata* community
- ■ *Podocarpus-Erica mannii-Asplenium friesiorum community*
- ◆ *Polyscias-Carapa grandiflora-Neoboutonia* secondary community
- ◆ *Newtonia-Parinari Secondary Forest* (low stemmed variant)
- ◆ *Macarango-Psychotrietum mahonii* Habiyaremye (1997)
- □ *Syzygium parvifolium-Alchornea hirtella community*
- ◆ *Erica mannii-Faurea-Aristida adoensis community*
- ▮ *Maesa lanceolata-Arthropteris monocarpa-Macaranga kilimandscharica* community
- ▮ *Symphonia globulifera-Strombosia scheffleri-Measa lanceolata community*
- ▮ Low stemmed *Neoboutonia macrocalyx-Macaranga* secondary community
- ◇ *Beilschmiedia rwandensis-Alchornea hirtella-Warneckea walikalensis* community
- × *Erica mannii-Microlepia speluncae-Breutelia diffracta* edaphic community
- ● *Psychotria mahonii-Maesa lanceolata-Xymalos monospora* community
- ● *Macaranga* dominated secondary community
- ● *Carapa grandiflora-Alangium chinense-Musanga leo-errerae* secondary community
- × Standard tree secondary community
- ● *Podocarpus latifolius-Rapanea-Mimulopsis excellens-Isoglossa vulcanicola* community
- ■ *Parinari excelsa-Ocotea usambarensis-Chassalia subochreata* community
- ▨ *Macaranga kilimandscharica* secondary forest
- ● *Myrianthus holstii-Shirakiopsis elliptica-Carapa grandiflora* community
- ● *Podocarpus latifolius-Isoglossa vulcanicola-Pilea rivularis* community
- ■ *Isachne mauritiana-Maesa lanceolata-Xymalos monospora* community
- ◆ *Shirakiopsis elliptica* standard tree secondary forest
- ◆ *Dombeya rotundifolia-Polyscias-Acanthaceae sp. XII* community
- ● *Celtis gomphophylla-Microcos mildbraedii-Carapa* spec. nov. community
- ■ *Hagenia abyssinica* dominated secondary community
- ▨ *Syzygium guineense-Symphonia globulifera-Lasianthus kilimandscharicus community*
- ◆ *Hagenia abyssinica-Erica mannii-Lycopodium clavatum* successional community
- ◆ *Syzygium guineense-Macaranga kilimandscharica* community
- ▮ *Xymalos monospora-Symphonia globulifera-Myrinathus holsti community*
- ● *Cleistanthus polystachyus-Carapa grandiflora-Acacia montigena* community
- ● *Erica mannii dominated ecotonal community*
- ▮ *Magnistipula butayei-Macaranga kilimandscharica-Carapa grandiflora* community
- ● *Xymalos monospora-Macaranga-Isachne mauritiana* community
- ● *Macaranga-Chassalia subochreata-Mimulopsis excellens* community
- ■ *Newtonia-Parinari* Secondary Forest
- ■ *Strombosia scheffleri-Carapa grandiflora-Mimulopsis solmsii* community

Figure 4.67 A - C: The plant communities developed under 3.2 are depicted in the biplots stemming from the variation partitioning approach with three groups. Here, CCA was used. Pane A illustrates the separation of the communities along axes one and two. Pane B shows axes one and three, and pane C axes two and three. The biplots are shown on page 343 and 344.

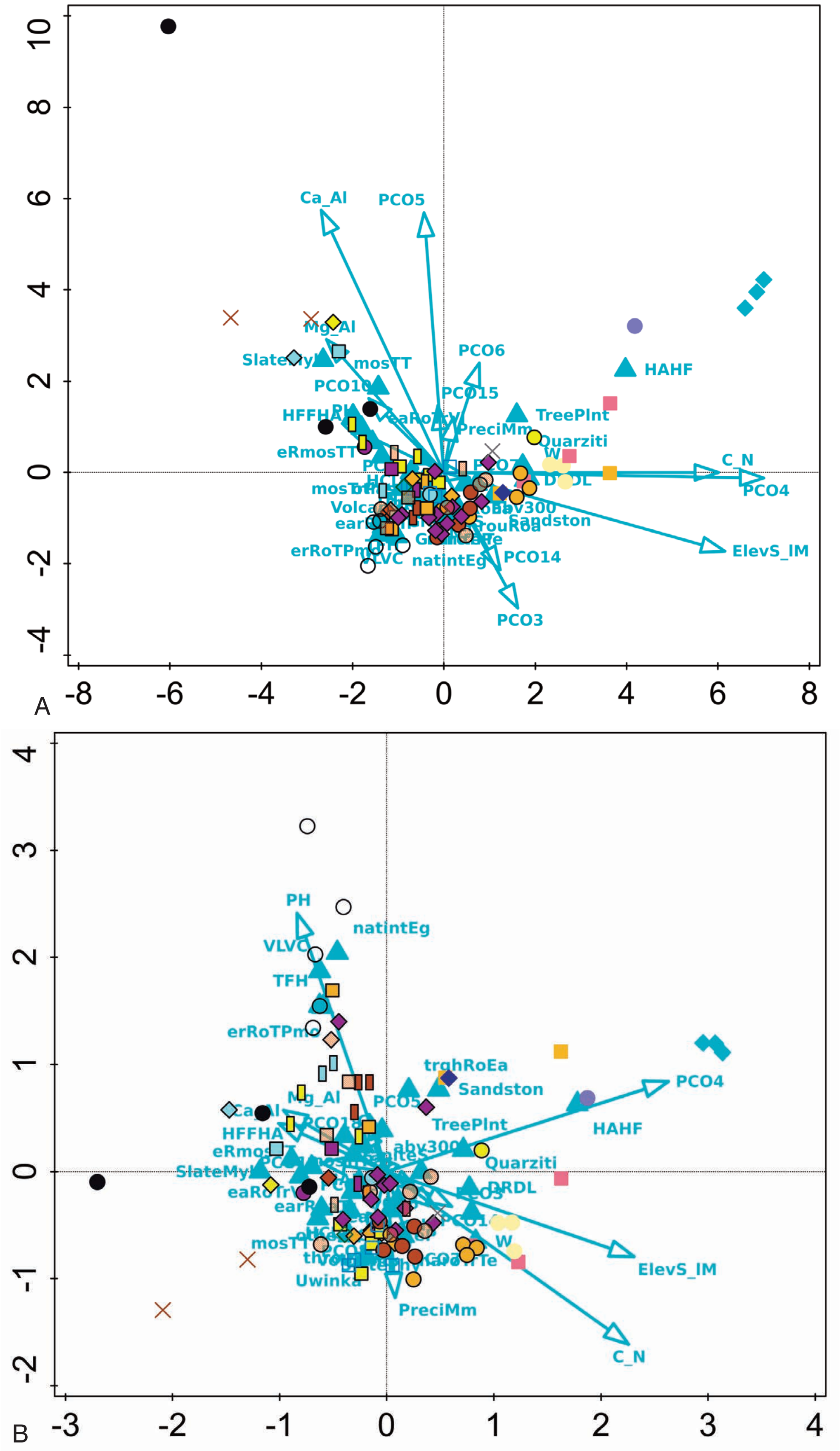


Figure 4.67 A - B: Biplots illustrating axes one and two (pane A) and axes one and three (pane B). The legend is shown on page 342.

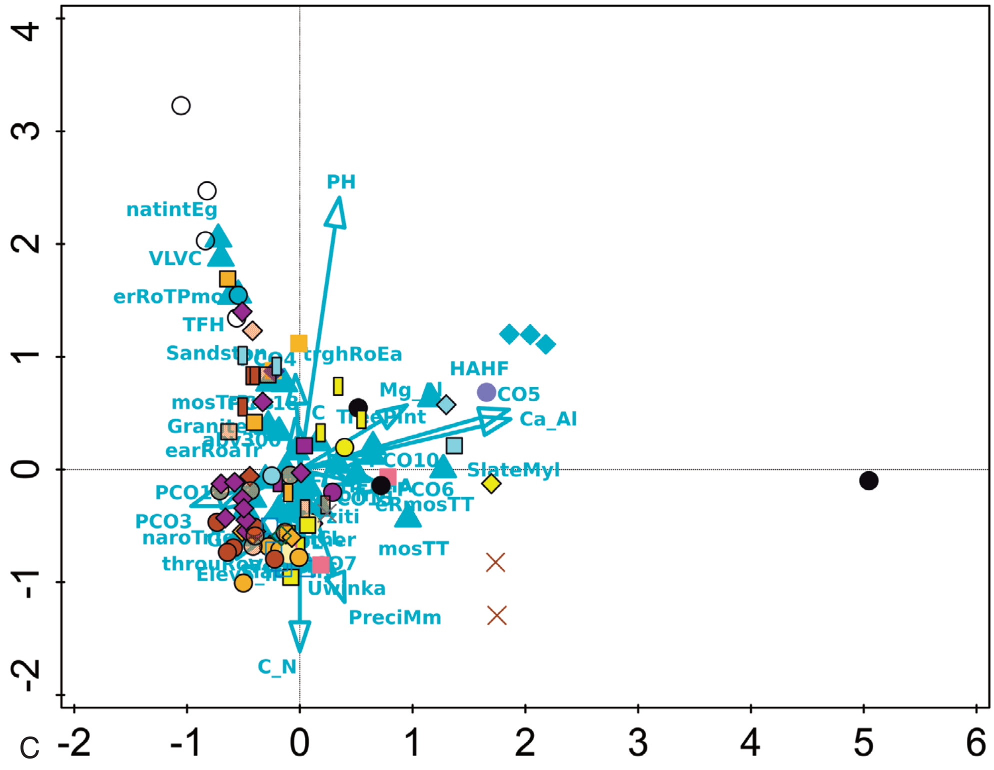


Figure 4.67 C: Biplot illustrating axes two anf three. The legend is shown on page 342.

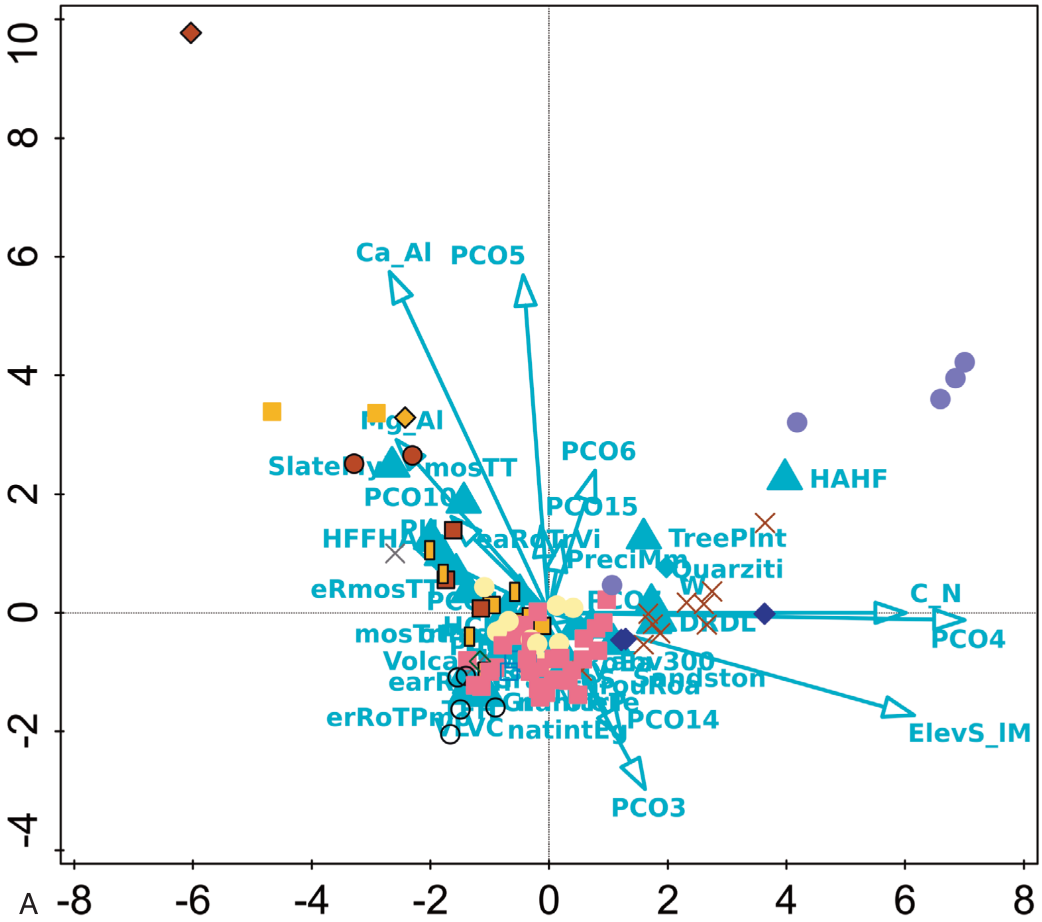


Figure 4.68 A: The plant supra-communities. The biplot is based on CCA. Axes one and two shown.

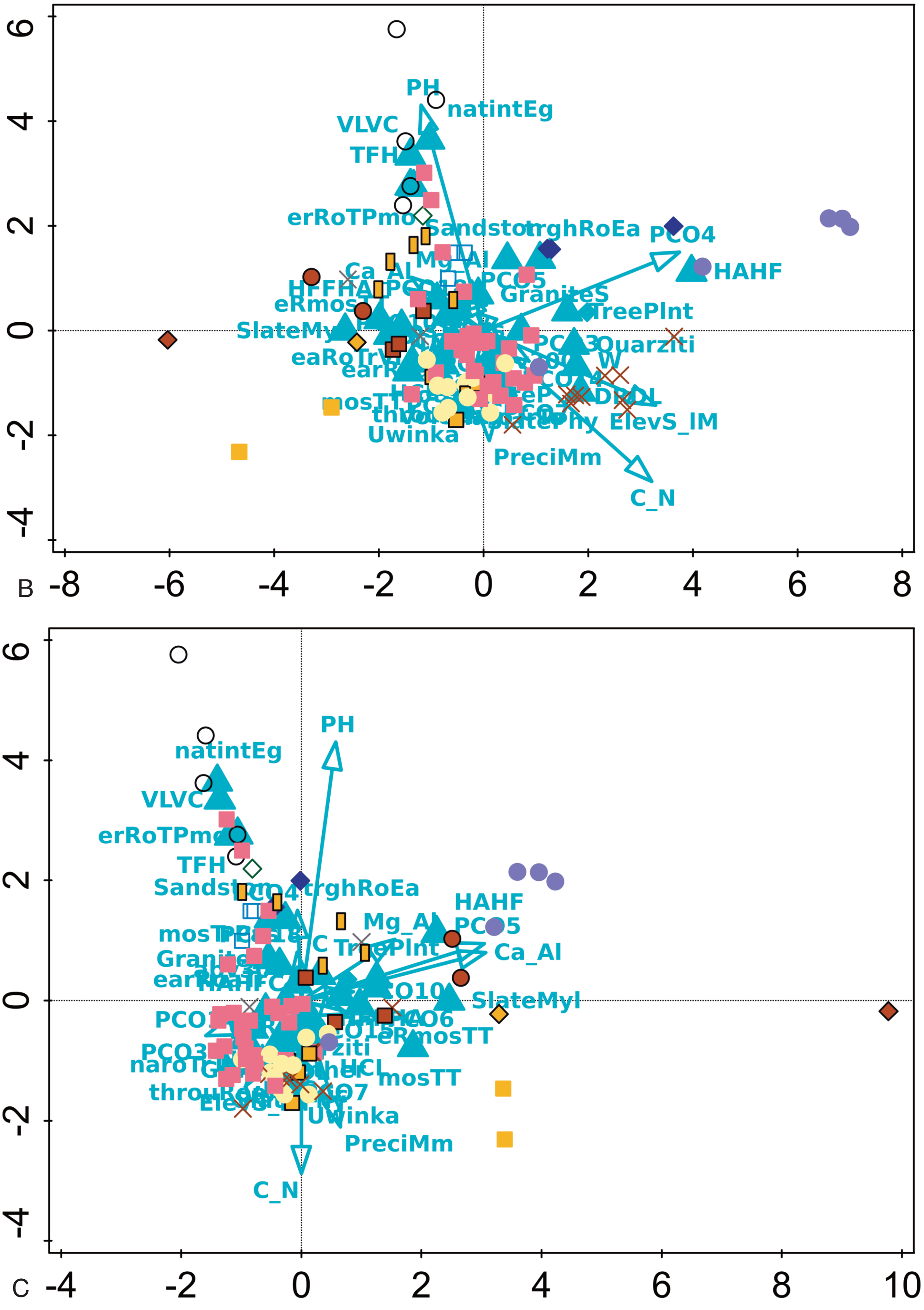


Figure 4.68 A - C: The plant supra-communities developed under 3.2 are depicted in the biplots stemming from the variation partitioning approach with three groups. Here, CCA was used. Pane A illustrates the separation of the supra-communities along axes one and two. Pane B shows axes one and three, and pane C axes two and three. The legend is given on below.

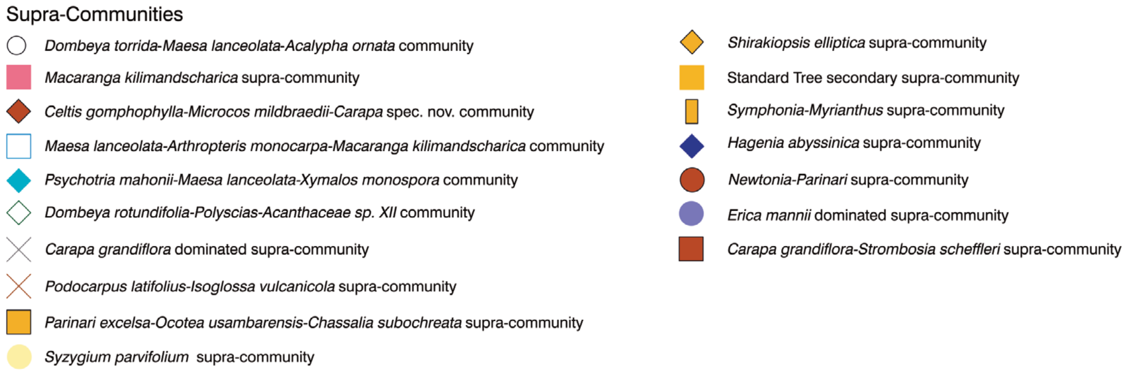


Figure 4.68: The symbols used to illustrate the supra-communities as developed under 3.2.

4.3 Direct Ordination vs. Indirect Ordination

When the results of direct and indirect ordination are compared, some differences in the relevant independent variables become apparent. While during indirect ordination the concentrations of Al, Mg and Ca appeared as of explanatory power, it is the ratios among them that gained significance during direct ordination and forward selection. While the topographical wetness index (TWI), the inclination and the insolation showed minor impacts during indirect ordinations, they never even appeared as of importance during the direct approaches to ordination. The most likely explanation to these occurrences may be found in the sequential partial process or forward selection to find the independent variables with the most impact, in other words, the residual variation in the data could not be sufficiently explained by the factors mentioned.

Albeit the impact of the variables that showed little importance in the course of the indirect ordinations is not reflected in the results of the direct ordinations, the factors should not go unnoticed. Soil moisture, for instance, has a significant impact on species composition and may be of crucial importance in future studies. Exposure at equatorial latitude may be of little importance, but in the rugged topography of the study area differences in the amount of radiation received may still result.

The samples determined under 3.1 to have an increased contribution to beta diversity remained conspicuous during the ordination analyses. In the indirect ordinations, the samples in question were only conspicuous when looking for outliers. After adjusting the method as described under 2.6.1.1, they no longer appeared in any particular form. While in the unimodal approaches the impact made the removal of three of the samples necessary (10_{NU}, 57_{C}, 60_{C}) and the other samples retained quite a strong impact, the tb-RDA and db-RDA based analyses were less impacted.

5 General Discussion

In the previous sections, we clarified the variables from whose correlations with species distribution possible influences of environmental variables on the species composition could be deduced. We also found that environmental variables and species distribution are spatially structured and that there is a high degree of agreement between both structures. In this section, the derivable correlations in regard to the identified species communities are outlined. At this point, we will start with the global trend and the broad scale structures highlighted before and discuss those with respect to vegetation and the individual forests. We will then move on towards the finest scales surveyed.

As may have been inferred without multivariate methods, the global scale models the differences between the single forests, e.g., Gishwati, Cyamudongo and Nyungwe. The global spatial trend is mostly defined by the geology, soil type, precipitation, elevation a.s.l. and increased pH-values in Cyamudongo and Gishwati Forests, as well as the lowest [C]:[N] ratios measured in the survey, which are—with very few exemptions—also only found in both forests. If the correlations to the forest matrix found are spurious, i.e., are an artifact of the sampling design, cannot be completely untangled here. More data has to be collected using a sampling scheme which provides the option to separate the impact of environmental and spatial variables more clearly.

5.1 The Communities of Gishwati forest

In particular, Gishwati Forest is set apart by the vertic luvisols/vertic cambisols, which at least within this survey are only found here. The same holds true for the terric / fibric histosols. Both of which then harbour the *Dombeya torrida*-*Maesa lanceolata*-*Acalypha ornata* community. As has been stated earlier, this community can be ascribed to the Polyscion fulvae. This alliance, according to Lebrun & Gilbert (1954), is of mesophilic (mesothermic) character. Despite confirming this fact, the Gishwati plots are further set apart by pH-values aggregated at the upper end of the survey's scale, and [C]:[N] ratios that do not exceed the mean value. It has been pointed out earlier that the [C]:[N] ratio signifies environmental conditions and the species' adaptations to them rather than being a mere independent factor. Nevertheless, significance of that factor is maintained after partial analyses (Tabs. 3.30, 3.31). Thus, some further investigation is endorsed. The environmental conditions might give some clue as to the dissimilarity of the community and thus its, so far, implausible incorporation into a supra-community. Resorting to the ordination results, the community has been reasonably well depicted by db-RDA. Along the first three axis the samples have been placed in close proximity and reasonable inferences can be drawn. Still, erroneous interpretations will occur without consulting the actual values of the impact variables. With tb-RDA the community is best depicted along axes two and three, while along axis one the differences in Mg:Al and distance to the forest edge in form of a spatial predictor might be the reason for the distances between community members. Canonical correspondence analysis set this community apart reasonably well along axes one and two. Inferences towards impacting variables are not possible from the diagrams.

Yet another community originating exclusively from Gishwati Forest and including *Maesa lanceolata* in its name, is the *Isachne mauritiana*-*Maesa lanceolata*-*Xymalos monospora* community. The similarities to the *M. kilimandscharica* dominated communities have been discussed under 3.2.13. Given the differences in species composition and stand height, the origin here may be presumed in the differing geologies and soil types. This, however is contradicted by most of the samples forming the *M. kilimandscharica* dominated secondary community, which are situated in the same soil and geological conditions. If the slightly lower precipitation in Gishwati forest has any impact in this regard, remains unsubstantiated for now as well. Further environmental and soil parameters do not lend themselves to speculations. The diagrams based on db-RDA recover the community reasonably well, although it is not clearly set apart from the other samples. The two plots comprised in this community are depicted further apart by the ordination based on the soil parameters. The underlying reason seems to be a difference in Mg:Al. Based on variation partitioning using three groups of explanatory variables, tb-RDA yields comparable results. The results stemming from CCA do not advance insights in the relations between the community at hand and the independent variables.

Despite being well distributed across all forests, in this study, *Symphonia globulifera* shows its main abundances in the Gishwati and Cyamudongo Forests. A species combination warranting the *Symphonia globulifera*-*Strombosia scheffleri*-*Maesa lanceolata* community only occurs in Gishwati Forest. With moderate Aluminium concentrations, the samples are not substantially different from the other Gishwati samples. With distances from the forest margin around one kilometre, the samples are the most distant ones from the forest edge in Gishwati. With respect to the differences to other forests, nothing can be added to the afore mentioned factors. Throughout the survey, *Maesa lanceolata* clearly shows its main abundance in Gishwati forest and around Bweyeye, so at the upper end of the lower level and the lower end of the mid-level of the montane rain forest. Some minor occurrences can be found in Cyamudongo forest, at Gahurizo, Gisovu and on Mt Bigugu towards 3000 m a.s.l. Although much less frequent, the same holds true for *S. scheffleri*, except for the occurrences in higher altitudes. Thus, the community might be found on granitic rock with inclusions from sediment rock covered by haplic ferralsols/ferric (haplic) acrisols of pH values around 3.6 experiencing quite low precipitation in the mid-level of montane rain forest. Distance based RDA barely recovers the community along axis two and inferences towards factors impacting species composition have to be drawn very carefully. Based on Hellinger transformation, RDA achieves the same unsatisfactory results. Doing a reasonably well job, CCA likewise places the samples in close proximity. A plot of axes two and three gives the best picture but does not allow for reliable inferences.

Held together by a good measure of caprice, the *Xymalos monospora*-*Symphonia globulifera*-*Myrianthus holstii* community bridges the Cyamudongo and Gishwati Forests. The ordination results barely recover the community, with the best results given by axes two and three (Figs. 4.67 C, 4.65 C). With most of the conditions being similar, the different geology does not seem to exert a noticeable impact. As such, the community might then be found under mesothermic conditions on humic acrisols/humic (ferralic) cambisols with pH-values between 3 and 4. Precipitation is comparatively low, so are the [C]:[N], [Mg]:[Al] and [Ca]:[Al] ratios. The distance to the forest margin varies between 240 and 310 metres, while the matrix is open, and in Cyamudongo, presents earth roads running through the forest. The secondary character of the samples may exhibit a transitional, successional state or may be at an equilibrium, which might be held up due to edge effects (LAURANCE, FERREIRA, MERONA & LAURANCE, 1998). Similarities in species composition allow for a combination with the afore mentioned *Symphonia globulifera*-*Strombosia scheffleri*-*Maesa lanceolata* community into the *Symphonia*-*Myrianthus* supra community. In the final variation partitioning approach based on tb-RDA, the samples are depicted along axes two and three at least in some proximity. The graph illustrating axes one and three and the graph showing axes two and three stemming from CCA, give the same idea. Whether the differences in species combination arise from the proximity to the forest edge or if the similarities in species combination allow for the consolidation into one species community necessitates further data collection. Despite the different geology, conditions are rather similar at all of the plots. The samples containing the *Symphonia*-*Strombosia*-*Maesa* community are set apart by a higher distance from the forest edge as well.

The *Macaranga kilimandscharica* secondary community established by FISCHER & HINKEL (1994) and described under 3.2.29 is another example of a purely "Gishwatian" occurrence. The sample size might be too small to subsume the community under HABIYAREMYE'S (1997) Macarango-Psychotrietum; however, as mentioned under 3.2.28, even comprising the indeed very similar samples from Nyungwe Forest, the association is not applicable at this point. Again, the samples from Gishwati present not only a species composition, which disagrees to a considerable extent with comparable samples from the other forests, but they are also of lower growth. Despite barely recovering the community, the ordinations lead to an erroneous judgment in terms of the impact variables, which may bring the dissimilarities about. The data collected does not give any clue to the differences in species composition and stand height.

Exclusive to Gishwati Forest as well, the *Dombeya* cf. *rotundifolia*-*Polyscias*-*Acanthaceae* sp. XII community might be an artefact of undersampling. An explanatory basis to the species combination found could not be established on the independent variables recorded. In furtherance of the assumption that it is indeed *D. rotundifolia*, the shallow soil and the granitic rock may give some implication.

Sample 94_{Gw} is part of a widespread community already recognised by HABIYAREMYE (1997). The Macarango-Psychotrietum could be found mostly in the eastern part of Nyungwe Forest with the exemption of samples 9_{NU}, 11_{NU} and 32_{NB}. Differing from most of the samples from Gishwati, sample 94_{Gw} is situated on vertic luvisols/vertic cambisols. Close to the edge of the forest bordering directly on an earth (now tarmac) road with an open mosaic of trees and pasture as a matrix, the consideration is not dismissed as to whether the continued existence of the secondary character of the community is thereby enforced. While the other parametres are quite comparable, it may be noteworthy that most of the samples from Gishwati that have an increased [Al] are harbouring *M. kilimandscharica* in higher abundances.

While FISCHER & HINKEL (1994) declared that all of the vegetation in Gishwati Forest is of secondary nature, HABIYAREMYE (1997)described the Carapo-Beilschmiedietum as a primary community. During the field work for this survey, neither was *B. rwandensis* found nor were the abundances of *C. grandiflora* sufficient to describe the above-mentioned community. Since no direct coordinates of HABIYAREMYE'S (1997) samples are available, confirmation of primary vegetation still being present in Gishwati Forest cannot be given at this point.

5.2 The Communities of Cyamudongo Forest

Though many species are shared between the separate forests and—in fact—communities, Gishwati Forest without a doubt, holds species combinations that are unique. The same might be said about Cyamudongo Forest. Before explicating the relations between environmental factors and species assemblies, it must be noted that most of the unidentified species are found here. The only survey carried out that explicitly described the species inventory of Cyamudongo Forest (FISCHER & HINKEL, 1993), briefly illustrates the vegetation units which may be encountered and relates them to the common altitudinal zonation described from Nyungwe forest. Hence, only a few descriptions of the vegetation exist, and new ground was broken in relating species communities to environmental conditions.

The attentive reader has noticed that almost none of the samples from Cyamudongo Forest show any significant overlap in species composition to allow for the establishment of a joint community. There too are no communities composed of samples from Cyamudongo and Nyungwe forest. Moreover, most of the samples from Cyamudongo Forest have remained as singletons.

Cyamudongo Forest is characterised by an even lower elevation a.s.l. than Gishwati Forest and precipitation does not exceed 1700 mm/a. While most of the samples are found on humic acrisols/humic (ferralic) cambisols, some are found on humic (dystric) cambisols. The latter was found to be statistically insignificant throughout all analyses carried out. While increased [Mg]:[Al] ratios can be observed in two of the Gishwati samples, the rate distinguishes most of the Cyamudongo samples. Like Gishwati Forest, Cyamudongo is set apart by geology. Although slate, mica-slate and mylonite rock can also be found at the westernmost edge of Nyungwe Forest.

Although described in Rwanda, *Elaeodendron* cf. *buchananii*, so far, has not been found in Cyamudongo Forest. The two communities described under 3.2.4 are rather hard to categorise and have, thus, only been merged as a result of the global cut of the dendrogram stemming from UPGMA. Both are found on humic (dystric) cambisols, a feature which differentiates the samples, but which has also been found statistically insignificant. Even if placed in some distance from each other, the samples are well distinguished on axes one to three by CCA (Fig. 4.67 B). The fact that most of the samples from Cyamudongo Forest, i.e., situated on the geological basis mentioned above, exhibit the highest [Ca]:[Al] ratios within the survey, leads to a distortion of the ordination diagrams. From the graph (Fig. 4.58 A) it appears that samples 49_C and 50_C feature some of the highest [Ca]:[Al] ratios when, in fact, both samples have very low ratios. The same is valid for the td-RDA to a lesser extent. From the CCA derived scatter plot, it may appear that both samples show elevated pH-values. Although the samples from Cyamudongo Forest are at the very top of the pH scale, both samples are situated at the low end of the scale with sample 49_C being even below average. These conclusions can be drawn from both analyses, whereby tb-RDA places both samples further apart from each other. What holds true for all the samples from Cyamudongo Forest is that the [C]:[N] ratios are among the lowest throughout the whole survey. Here the samples at hand, 49_C and 50_C, display the highest values among the Cyamudongo samples.

As it sits at the edge of the forest bordering on a tree plantation, sample 48_C remained a singleton throughout the analyses. Set somewhat apart by CCA, db-RDA and tb-RDA along axis two, the sample shows a fairly elevated pH-value and [Ca]:[Al] ratio along with, by comparison, a slightly above average [Mg]:[Al] ratio. As such, the data available does not permit any conclusion other than that *Shirakiopsis elliptica* can predominantly only be found in the western part of Nyungwe National Park and here especially in Cyamudongo Forest and at Gasumo. Further specimens can be found around Bweyeye and with minor occurrences at Gisakura. All of the samples were taken from the lower level of the montane rain forest. If causal dependencies exist between the around and below average [C]:[N] ratios, the circumstance that all of the samples are from below the 300 m impact sphere of edge effects (LAURANCE ET AL. 1998) and species combination, especially the occurrence of S. *elliptica*, cannot be ascertained without additional data.

The two *Newtonia-Parinari* secondary communities are well recovered by both the CCA and tb-RDA ordination approaches. Distance based RDA placed both samples quite far from each other. Along axes one and two CCA separates both from most of the Cyamudongo samples and places them in close proximity to each other and to the previously described communities. The environmental and soil conditions are quite similar between both samples. Whether or not the differt soil types and the earth road cutting through the forest, in combination with the more open matrix near sample 55_C, brought about the lower canopy, cannot be asserted at this point.

After the removal of several samples from the CCA based model (see paragraph 4.2.3), plot 56_C exhibits the highest [Ca]:[Al] ratio throughout the survey. If this finding and the close proximity to the forest edge may add to the elevated abundance of *C. gomphophylla* cannot be determined here. Since sample 49_C holds the species to an appreciable abundance as well, such an inference would be unreasonable. Nevertheless, *Carapa* spec. nov. can only be found in Cyamudongo Forest. *Microcos mildbraedii* and *C. gomphophylla*, despite some minor occurrences around Gisakura and Gasumo, also have their centre of abundance in Cyamudongo Forest. Thus, the *Celtis gomphophylla-Microcos mildbraedii-Carapa* spec. nov. community seems, for now to, be restricted to the combination of impact factors predominant in Cyamudongo Forest.

The *Ficus* sp. IV-*Croton* cf. *macrostachyus* community found in plot 57_C is a product of both, undersampling and insufficient knowledge about the species inventory of Cyamudongo Forest. The site has the highest pH-value measured in the survey as well as a rather low [Al], which results in a high [Ca]:[Al] ratio and an elevated [Mg]:[Al] ratio. If the close distance to the forest edge in combination with a rather open forest matrix contributes to the secondary character would be the objective of further research.

The *Mimulopsis arborescens-Alangium chinense* secondary community represented only by plot 60_C, was found in soil with extremely high [Ca]:[Al] and [Mg]:[Al] ratios, while its pH is the second highest measured within the survey. Other than that, the sample is quite close to the forest edge bordering the same matrix as the sample before. Although pure stands in the understorey are not rare in the area, inferences on the relationships between the explanatory parameters and species combination in this sample would be mere speculation.

5.3 The Communities of Nyungwe Forest

While Cyamudongo and Gishwati Forests are set apart on the global XY scale and the broad scale, only some of the broad scale spatial predictors but mainly the medium scale variables model the variation within Nyungwe Forest. The possible relationships and implications will be outlined subsequently.

After testing for the conditional effects of the variables shown to have an impact, it can be seen from the graphs (Fig. 4.57) that, for Nyungwe Forest, precipitation and elevation divide the samples into distinct groups. Yet, the [C]:[N] ratio and the distance to the forest margin present interesting impact variables as well. Along axis one, the separation between the Nile and Congo sides of the watershed is more or less well traceable. The rather coarse spatial structures represented by PCO.4 and PCO.5 seem to display more than just the separation between the Nile and Congo sides of the watershed (Fig. 4.54 C, D). The *M. kilimandscharica* dominated communities are more or less restricted to the Nile side of the watershed. They are mainly characterised by a precipitation lower than the annual average. The communities containing *M. kilimandscharica* found on the western side of the forest show higher precipitation and, at the same time, a lower abundance of the species. The altitudes a.s.l. range around the survey's average and are thus mainly from the mid-level of the Rwandan Afromontane rain forest. The [C]:[N] ratio, likewise, variates around the average of the survey with a tendency towards the upper end of the scale.

The *Syzygium parvifolium*-*Macaranga kilimandscharica* community is best depicted by a plot of axes two and three (Fig. 4.65, Fig. 4.67). The samples from Uwinka are positioned in close proximity to each other, while the sample from Gisakura is separated along axis two. Along axis three, the samples from Uwinka and the Gisakura sample are positioned quite close together. Here, the four samples from Uwinka are, with one exception, separated from the rest of the samples taken at Uwinka. Although, all samples are far from the edge of the forest, one of Rwanda's main roads cuts through the forest at a maximum of 200 m from the samples. Even in conjunction with the other impact variables being comparable or equal, the proximity to the road puts forth the question of whether said proximity impacts species composition. The sample from Gisakura is not positioned close to a road but close to the Nyungwe Forest lodge within 60 m from the forest edge. Within the samples from Gisakura, all of the other parameters are comparable. Therefore, the same question arises at this point; is the distance to the forest edge the decisive factor in terms of species composition. When circling back to the species community at hand, the warmer mean annual temperature, the different soil type and geology, the higher pH as well as the lower [C]:[N] and [Mg]:[Al] ratios at Gisakura do not seem prohibitive to its establishment. In summary, the community can be found on rather acid soils with a pH not exceeding 3.60. The [Mg]:[Al] ratios are very low, i.e., [Al] is elevated. The [C]:[N] ratios show a tendency towards the upper end of the range measured. Precipitation is rather elevated, although quantities could be as low as 1800 mm/a. Found at Uwinka, these amounts of precipitation are accompanied by an elevation a.s.l. around 2500 m. At Gisakura, the relationship is inverted; the stand is situated at the lower level of the montane rainforest, while precipitation is far beyond average. Accordingly, the interplay of altitude and rainfall seems to be of major impact here. The distance to the sources of disturbances s.l. may also be a driving influence, but confirmation of this hypothesis necessitates additional data.

Another community which can be differentiated at the medium spatial scale is the *Parinari excelsa*-*Ocotea usambarensis*-*Chassalia subochreata* community. Found around

Uwinka and Gasumo, the community is restricted to the western side of the watershed. All of the samples exhibit low [Mg]:[Al] ratios due to elevated [Al] and low pH values. Geology only differs in the admixture of phyllonite and mylonite around Uwinka and Gasumo, respectively. The [C]:[N] ratios are close to the average and thus likewise do not lend themselves to speculations towards causal relations in terms of species composition.

Separated quite well along axis two, the samples from Mt Bigugu and Mt Muzimu follow the environmental pattern handed down since the first exploration of the Rwandan montane rain forests (Engler, 1910) (Figs. 4.65, 4.67). Additionally, low soil pH values signify the samples from Mt Bigugu. The samples from Mt Muzimu, on the other hand, exhibit soil pH values a little above the average measured. If this is due to the partly different soil types in conjunction with lower annual precipitation cannot be elucidated here. Although not mentioned until now, it is apparent that albeit both mountains offer considerably similar conditions, no stable foundation for a species community found on both peaks could be established. The two parameters mentioned above are likely to have had an impact since precipitation and at least the humic acrisols/humic ferralsols prevalent on Mt Muzimu remain of statistical significance even in the partial approaches. A definite conclusion on the reasons for the only slight overlap cannot be given here. An attribute both of the mountains share, is the elevated [C]:[N] ratio. Although there is a clear correlation between the [C]:[N] ratio and lower temperatures, as well as a typically above average precipitation in conjunction with low pH values, the impact of the rate itself still appears evident. This impact may, in particular, be exerted on the species of the lower vegetation strata which at least in the current study are only found within the respective samples. If that truly is the case or if the conclusion in respect to the herb and shrub strata would likewise be circular cannot be elucidated here. It remains though that the species present in the tree strata carry environmental control when it comes to the vegetation layers below.

Since the increased [C]:[N] ratio is a feature predominantly of the soils and vegetation of higher altitudes and will be of importance in future developments in relation to the changing climate, its significance will be discussed here in a wider context. As has been stated earlier, the reasoning that the vegetation found on soils with an elevated [C]:[N] ratio can be distinguished into species communities by said increased ratio would be rather circular.

The first to ascertain an impact of the variable using indirect ordination methods was Habiyaremye (1997). He attributed the elevated [C]:[N] ratios to the high acidity of the soils as the main reason, but did not give any direct measure or citation for this (ibid.). Whereas Kauffman et al. (1998, p. 16) stated that no correlation was measurable in their survey between organic carbon content and soil reaction for acid soils and between [C] and exchangeable aluminium. For the survey at hand the [Al] was not related to the C:N ratio. On the other hand, an increased correlation was found between the [C]:[N] ratio and pH despite the acid soils and the undercutting of the threshold of a pH of 5.5 given in Kauffman et al. (1998, p. 16). It can also be seen from the results of the current survey, that soil acidity is related to elevation. Thus, it has been argued that low pH values may impact the [C]:[N] ratio via impeding soil biota and decomposition, but the climatic conditions in relation to the altitude a.s.l. are one of the driving forces for soil acidification and low decomposition rates (see paragraph 4.1).

Furthermore, it is not clear from Habiyaremye's (1997) work if he as well recognised the relation between the [C]:[N] ratio and the climate conditions in higher altitudes and the generally increased [C]:[N] ratio within the foliage and with that in the litter at higher elevations.

Van der Heyden (2016) demonstrated that in the upper soil layer [C] tended to increase with increasing altitude and that especially the [C]:[N] ratio showed a significant increase. The author (ibid.) also demonstrated the significant increase of [C]:[N] with altitude for the foliage and litter layer.[1] Albeit the origin of an altered [C]:[N] ratio might be found in rather complex relations not fully researched yet (van der Heyden, 2016), it is the [N] which, in the end, presents the limiting factor[2] (see: Taveirne, 2016). Following Kauffman et al. (1998), high [C]:[N] ratios stem from slow decomposition and low rates either characterise fast decomposition or low organic N content in the vegetation. While the authors concede that the following values are mainly used in temperate zones, they indicate a nitrogen deficiency if the [C]:[N] ratio exceeds 12 to 14 (ibid.). Most of the pertinent samples in the current work surpass these values and some are even above the mean values given by Kauffman et al. (1998, p. 14) for the dominant soils in the humid tropics. Thus, the species inhabiting high altitudes do have an increased share of carbon in their leaves in combination with a smaller nitrogen share. In conclusion, the increased soil [C]:[N] ratio is brought about by the harsh environmental conditions at high altitudes and the plant species which are adapted to them. The more nutrient conservative species are therefore adapted to a more closed N-cycle (less nitrification, mineralisation and leaching) due to the overall conditions at high altitudes (Taveirne, 2016). Although this means that the [C]:[N] ratio is rather a result of the climatic and edaphic conditions, as well as the litter from the vegetation on site adapted to the high-altitude conditions, the ratio gives some evidence of the nitrogen concentration as the limiting factor which in turn impacts plant life. Moreover, from here, the question emerges towards the consequences of the changing temperature and precipitation regimes. If mineralisation would be accelerated and the limitation presented by [N] is alleviated, competition among species could lead to a decline of species now symbolising high altitude vegetation.

The relation found in the present study between *S. parvifolium*, further coriaceous and sclerophyllous species and the [C]:[N] ratio may thus not be used as a predictor of species communities. It is but rather an essential symptom of an environmental impact regime typifying high altitudes. The change of the C:N ratio and in particular the isotopic composition of nitrogen contents should be monitored to detect changes perhaps even before they manifest in changing vegetation (Craine et al., 2015 a/b; see also van der Heyden, 2016).

Albeit not asking the questions towards the origin and importance of the increased [C]:[N] ratios, Wekesa et al. (2018) noted that organic carbon concentration did not impact the abundance distribution of *S. parvifolium*, *P. latifolius* and further tree species in the Taita Hills in central Kenya.[3]

This, however indirectly, supports the notion that an inference from the soil condition to species composition would be rendered circular. Still, some scrutinisation of the supposed causalities is advisable.

Following the principle of the relative consistency of location, for now, the conjecture stands that the abundance of *S. parvifolium* is impacted by either heightened precipitation

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[1] Gharahi Ghehi et al. (2014) found evidence that nitrogen trace gas emissions might largely be controlled by biological factors, i.e., soil organic carbon and nitrogen content were positively correlated with emissions amount. Thus, corroborating the assumptions however indirectly.

[2] Phosphor seems not to be the limiting factor here. Citing Porder, Vitousek, Chadwick, Chamberlain & Hilley (2007), Taveirne (2016) suggests Phosphor to be more available due to new sources becoming accessible by tectonic uplift, erosion and landslide activities. This would be explicative of the loss of explanatory power of Phosphate in the present study.

[3] However, within the survey at hand total carbon was measured. Since the parent material is of low carbon content, the increase in the ratio should be attributable to an elevated organic carbon fraction.

or elevation, whereby elevation may not exceed ~2750 m for the species to be prevalent. *Syzygium parvifolium* can still be found towards the summits of Mts Bigugu and Muzimu, but the dominance here is then with *P. latifolius* and *E. mannii*. For both of the species, the interactions discussed above may be even more pertinent.

This then concludes the identification of possible relations between single species communities and the suites of factors impacting species composition of the respective communities. The communities thate were not previously discussed are either not well separated or consist of singletons. In both cases, further inferences would be purely speculative. Nonetheless, some general notes are in order.

5.4 Some remarks on Particular Impact Factors

In the following paragraphs we will delve further into the discussion of individual factors. Here, we will also draw on the results of the preceding partial concepts, since in the last variation partitioning procedure categorical variables could only be included as a whole. Furthermore, some light will be shed on individual factors the impact of which may not be readily accepted and discussed.

5.4.1 The Medium Scale and the Forest Matrix

The respective matrix of the forests seems to exert some impact. Considering that the forest matrix varies around the forest, it is of course spatially structured. During analyses diverse matrix types entered the selection only temporarily. These unstable results may be sign of a sampling artefact stemming from an uneven sampling design and spurious correlations to the other impact variables. While not all matrix types gained or kept statistical significance, few maintained explanatory importance. In general, both RDA methods resulted in more explanatory variables being statistically significant than in CCA. When it comes to the non-partial approaches, all three ordination methods found the Uwinka visitor centre, the road running through Nyungwe forest and the tree plantations in the buffer zone to be of significance. In addition, db-RDA recognised also an impact of the earth roads running through the forests and of the earth roads at the border of the forest in connection to tea plantations. Using tb-RDA, a buffer zone consisting of a mosaic of tree and tea plantations connected to an earth road attained significance as well. If the matrix states with remaining significance after controlling for the effect of the soil parameters, Uwinka, natural interior edge, tree plantation and mosaic of trees and pasture, are of importance in the real world or if the effect is spurious and a mere artefact of the sampling scheme can only be ascertained on a wider data basis. Nevertheless, a short discussion seems appropriate.

The samples from around Uwinka are mostly quite well separated in the graphs. Since the conditional effects among the environmental parameters have been tested and the matrix state is still of statistical significance, either some unmeasured factor is present, or the interaction of several variables is thus detected. An unmeasured variable may be found in the history of the site. The presence of some spatial structure delineated by PCO.11 and PCO.12 (Fig. 4.56 H, I) is a hint to a possible variable that has so far gone unnoticed. Likewise, from the medium scale of spatial variation, PCO.7 and PCO.8 are somewhat negatively correlated with both of the spatial predictors above (Fig. 4.56 F,G). At this level, further relations to the forest matrix also seem evident (Fig. 4.64). As has been stated, when analysing the single impact factors, the matrix states including roads as well as the Uwinka visitor centre maintained their statistical significance.

The road running through Nyungwe National Park separates the samples close to it from the rest of the samples from Uwinka. Except for the markedly secondary character of the vegetation around Uwinka no further inferences seem to be warranted. In those cases where the forest matrix is comprised of a road or a road runs through the forest, only an equally general statement can be provided; the vegetation is of a predominantly secondary character.

While the matrix states comprising roads were of significance when their simple effects were tested, they lost their explanatory power only in the partial analyses. Hence, it still remains unclear whether the impacts of the roads exert most of their effect on the vegetation via the soil and for this reason have lost their significance in the partial analyses, i.e., after removing the variation in the species data explained by the soil factors, or whether they are artefacts of the uneven sampling design and never were of importance. In case of real impacts of the roads, a number of unmeasured variables present themselves. These influences might be of historical nature, be due to the fact that roads are a barrier to many ecosystem processes, stem from shifting processes in the soil or, most likely, altered the microclimate of the site. With the latter alteration, soil moisture could be impacted as well. An interesting point, which wistfully does not solve the above conundrum, is that all the matrix types containing roads have heightened VIFs, with the exemption of the main road cutting through Nyungwe. To elucidate the supposed relations a more extensive data basis would also be needed.

The mosaic of tree and tea plantations connected to an earth road can only be found near to two samples in Cyamudongo Forest which at the same time exhibit the highest pH-values of the survey. Is this occurrence incidentally and pH is “elevated” because of the warmer and drier climate or does the well-used road through the forest carry some effect 150 m into the forest? Chances are high that this effect is spurious, yet, as well in respect to the other matrix states, more data has to be recorded in order to warrant a reliable statement.

5.4.2 The Distance to the Forest Edge

The fact that the distance to the forest edge lost its statistical significance during CCA based variation partitioning does not necessarily mean that there is no impact. When taking a look at the broad and some medium scale spatial predictors, a significant correlation among them and edge-distance can be seen. This takes no wonder since the distance from the edge intrinsically is a spatial predictor. This also entails that the distance from the forest edge itself is not an impact variable, but only represents the spatial dependence of some environmental factors. Despite the risk of spurious relations to other impact variables, e.g., forest matrix states or the position towards the watershed, introduced by an uneven sampling design, a number of environmental properties vary with the distance to the forest edge. Which parameters are involved can only be determined on the basis of further data. Changes in microclimate are among the factors comparatively easy to measure, while direct anthropogenic impact is certainly more difficult to measure. Moreover, the distance from the forest edge may not only integrate unmeasured factors it might also integrate impact factors immeasurable in the field like interactions among plants or biota in general. Hence, the direct dependency of species composition on the predictor itself may have lost significance but its impact is mediated through a quantity of factors changing with the distance from the edge. Cadenasso, Traynor & Picket (1997) concluded that the effects and widths of such gradients are different for each factor and site surveyed. According to the authors, edge effects and width of edge zones also vary with edge exposure and nature of adjacent habitat (IBID., p. 779). In the work at hand exposure may not be of importance, still the position towards the watershed and elevation are certainly of importance in this respect. In respect to the adjacent habitat, the results of the current survey also yield some implications for measurable impacts on species distribution. While CADENASSO ET AL. (1997) described these effects for mesophytic deciduous forests of the northern hemisphere, WILLIAMS-LINERA (1990) found no impact on the vegetation beyond 20 m into a Panamanian forest (IBID. , p. 368). However, he stated as well that the definition of a forest edge depends on the organisms considered and mentioned an impact range of up to 500 m for some animals (IBID., p. 368). Another perspective given by the author is the dependence of edge effects on the age of the forest edge itself (IBID.). PARRA-SANCHEZ & BANKS-LEITE (2020) likewise found edge effects up to a range of 500 m into the forest that affected the vegetation of their study sites in the Brazilian Atlantic Rainforest. GEHLHAUSEN, SCHWARTZ & AUGSPURGER (2000), conducted research on edge effects in mixed-mesophytic forest fragments and attested microclimatic variables to differ in degree and distance over which an effect can be recorded. Their analyses indicate a range of influence of up to 175 m, where the main impact might be found below a range of 80 m. EWERS & BANKS-LEITE (2013) found adverse microclimatic effects for stands of the Brazilian Atlantic rainforest. The authors stressed that habitat fragmentation aggravates the effect and that the perimeter to area ratio is crucial in terms of how large an area is impacted by edge effects (IBID.). LAURANCE ET AL. (1998) even found impacts on tree mortality of up to 300 m into the forest. While the main effect on e.g., turnover rates can be found to about 60 m into the interior, the authors still noted an effect on vegetation dynamics within ca. 100 m of the edge in Amazonian habitats (IBID.). Once the size of forest fragments falls below ca. 100 to 400 ha, the importance of edge effects will drastically increase (LAURANCE ET AL., 1998).

Hence, these data can lend themselves to corroborate the inferences in the work at hand. Especially the soil pH values show a significant correlation to the distance from the forest edge as well as to some spatial predictors. An increasing pH value in conjunction with a decreasing distance to the forest edge has recently been discussed to be related with soil moisture by WEKESA ET AL. (2018). This finding can at least by inference be confirmed here. Moreover, it appears that certain types of forest matrix contribute to this relationship. When taking a look at figure (Fig. 4.57 C) it can be seen that the more open matrix states particularly the ones comprising roads are correlated to higher soil pH values. It should also be noted that despite the still visible impact after the indirect effects have been taken into account, soil pH does not affect all the species to the same extend.

WEKESA ET AL. (2018) found significant edge effects in the distribution and abundance of *A. gummifera*, *S. parvifolium*, *X. monospora*, *T. stapfiana* and *M. lanceolata*. Therefore, the hypothesis has been proven in a similar environment and merits further investigation.

Another observation that should be mentioned, is the loss of statistical significance of the environmental parameters not describing soil parameters when testing for the conditional effects within the CCA based approach. A fact that does not render these variables irrelevant. Instead, the spatially structured component of said variables is predominant (see Fig. 4.58, fraction f in the CCA based approach). The same is valid for the fraction solely explained by the spatial predictors. In the td-RDA approach both fractions (a & c) retained their statistical significance, albeit fraction c decreased to a $P = 0.023$.

In terms of the CCA based results, this entails also the loss of significance for the fine scale fraction of the spatial predictors, which by itself stayed significant in a partial analysis. This raises the question towards the validity of the statement pertaining to processes of community dynamics that may be responsible for the fine scaled structures to be significant. In light of the tb-RDA results, the unsettledness is somewhat ameliorated since significance is retained at least at the 98% level.

5.4.3 The Soil Parameters

For the relevant soil parameters, all the partial approaches resulted in the identification of pH, [C]:[N], slate with micashists and Mylonite, and humic acrisols/humic ferralsols as important factors. Partial CCA and partial db-RDA additionally recovered the [Ca]:[Al] and granitic rock/paragneiss/orthogneiss as influential, while partial tb-RDA in accordance with partial CCA added the sandstone/quartzite/metaquartzite/magmatic bedrock/quartz with slate deposits and the [Mg]:[Al] to the significant factors. Both RDA procedures included quartzitic/metaquarzitic geology, the volcanic rock, the limitation of the drillable soil depth by stone and the humic acrisols/humic (ferralic) cambisols in the group of factors of explanatory value. The inclusion of silty loam by db-RDA might by spurious since the only sample based on this soil texture type (10_{NU}) is vastly different from the other samples for a reason not included in the independent variables. Hence, ordination sought out the most differentiating factor. The [Al] and the granitic rock with inclusions of sediment rock were only discerned and included in the results by tb-RDA.

As has been stated, within the soil types only a few soils retained statistical relevance. In all of the methods the humic acrisols/humic ferralsols (HAHF) are of explanatory value. Neither is a particular community distinguished by the HAHF nor do specific species exhibit a markedly high abundance here. The seven samples found on this soil type are part of five different communities. Most of the samples are from around Gisovu and harbour *E. mannii* dominated vegetation. The sample from Gishwati Forest, with 2241 m at the lowest elevation a.s.l. at which such soil was found, shows a *X. monospora* and *S. globulifera* dominated community. Two of the samples, from the vicinity of Musebeya, hold a vegetation dominated by *M. kilimandscharica*. The rather low explanatory power of the soil type state impedes interpretation in general and especially the interpretation of the biplots. Here, the soil type sets the samples on Mt Muzimu apart, further inferences should not be made. The explanatory power of humic acrisols/humic (ferralic) cambisols (HAHFC) is equally as low. Almost half of the samples are situated on this soil type, many of which are dominated by *M. kilimandscharica* or the species at least occurs within the sample. Further inferences can neither be drawn from species composition of the samples nor from the ordination graphs. Hence, the results may hint on an impact of the soil types, yet more data needs to be collected to refute or approve a real impact.

The electrical conductivity, found of interest in the indirect analyses of the current survey, did lose its statistical significance during further analyses. Since one of the aims of this survey is to determine the possible relations underlying species composition and environmental factors, EC should at least be recorded until the data volume is sufficient to allow a reasonably reliable statement. An indication in this direction is given by the biased study of Wekesa et al. (2018) who found EC to be of significance. Since EC as well as pH are measurable in the field and both are related to the [N] (and therewith to SOM), they might be used as a proxy for the [N] to get a least a rough idea of the conditions on site. Whether the correlation is robust must be confirmed by further data.

During the explorative process, phosphor shortly gained significance during forward selection in a CCA based approach. Since the plant nutrient did not gain permanent statistical significance during analysis, the effect seems to be spurious. Van der Heyden (2016) as well as Taveirne (2016) stated that phosphor in the setting of the research area is unlikely to be a limiting factor. Both authors rest their statements on Tanner, Vitousek & Cuevas (1998) and Porder et al. (2007). In the context of the survey at hand, the effect of P is considered spurious, if the role of P is researched further in future studies remains the specific question to be answered by the researcher.

5.4.4 General remarks on soil conditions

At a first glance the, by comparison, larger impact of the soil parameters may come as a surprise. While temperature and altitude most often vary at a larger scale than the soil conditions, it should not come as a surprise that soil conditions govern species composition at smaller scales. In other words, the gradients in elevation and precipitation cause differences in vegetation. In large areas of the forest, however, these parameters do not vary. In areas where both are constant, the differences in species composition are more likely to be due to the soil conditions. Naturally, other processes like community and landscape dynamics or features of the terrain as well as anthropogenic impacts also are of importance.

In contrast, Omoro, Laiho, Starr & Pellikka (2011) and Wekesa et al. (2018) recently stated that soil conditions are not of particular impact on species composition. Albeit surveying afromontane forests, the authors dealt with rather short gradients when it comes to soil properties and focused their work on tree species rather than on vegetation as a whole (ibid.). Hence, their work gives valuable information on the distribution of certain tree species and on the impacts of edge effects, but should be taken with caution in respect to inferences on more comprehensive vegetation inventories and longer gradients in a more complete set of independent variables. While their comparison to a study from middle Europe lacks validity (ibid.), some general brief deliberations of potential dependencies between soil and vegetation in rainforests seem expedient.

For the Peruvian Amazon Tuomisto et al. (1995) found vegetation patterns to be impacted by soil conditions and demand spatially reliable data on soil and species distribution to guide conservation efforts. Ter Steege, Jetten, Polak & Werger (1993) likewise found edaphic factors to be of importance in terms of species composition in a watershed area in a neotropical forest. Already in 1976 Hall & Swaine found species patterns to be impacted by soil conditions in Ghanaian forests. Poulsen et al. (2005) concluded from their research at several sites of the Albertine Rift that altitude, pH and cation concentrations may have an impact on species distribution rather than historical factors. How this impact of soil conditions comes about and how the effect of leaching is counteracted is speculated on in the following.

In many tropical montane rainforests, topography is rather diverse, rugged and characterised by steep slopes that are often associated with high erosion, as in the present study area. Topography now impacts and, as Florinsky (2012) called it, naturally controls the spatial distribution of physical, chemical and biological soil attributes (ibid., p. 145).[4] Or as Duniway, Bestelmeyer & Tugel (2010, p. 9) stated; soil processes are controlled by landform properties which then regulate soil properties and hence cause variation among eco-

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[4] Florinsky (2012) gave numerous literature sources to which the reader may also be referred.

logical sites. From this, one could conjecture that the probability of the soil conditions in the current study area being of increased diversity is quite heightened.

BERN, TOWNSEND & FARMER (2005) raised the point that rock derived nutrients maybe replenished by advection in the soil column in tectonically active landscapes and by a topography that facilitates sufficient erosion. HALL & SWAINE (1976) also confirm that erosion and weathering play a major role. While VITOUSEK ET AL. (2003) elaborate on the role of erosion and topography for soil nutrient availability, PORDER ET AL. (2007) confirm the above findings, but focus solely on Phosphor. These findings are reflected in the results of VAN DER HEYDEN (2016) for Nyungwe Forest who stated that P does not seem to be the limiting factor. The element or its cations did not gain sustained significance in the current study and could not be taken into account to explain the variation in species composition.

Consequently, the quite diverse and active landscape of the current research area, with its distinctive topography, thus provides for a range of soil properties that may as well impact species composition to an extent surpassing that of rainforests in more uniform landscapes, especially those from geologically older and less active regions. So, had WEKESA ET AL. (2018) found longer gradients in soil parameters, their results may have been rather different.

5.4.5 The Fine Scale

Whereas the fine scale spatial predictors beyond PCO.12 were statistically significant in the ordination models seeking to explain variation in species data, they were not of significance when relating the environmental variables to space (see paragraphs 4.2.5.2 & 4.2.5.3). While there was still some significance at the 95% CI for the approaches comprising all the scales, when testing for the single effects of the fine scale section, statistical significance disappeared. Yet, some variation in vegetation is visible at that scale. Since the correlation to the species data remained significant, this may give testimony to the presence of local spatial correlation created by neutral biotic processes like random survival or reproduction (BORCARD ET AL., 2018; LEGENDRE & LEGENDRE, 2012). Thus, community dynamics, in general, are likely to cause variation at this spatial level rather than environmental control. As a result, parts of fraction c of each of the variation partitioning approaches with three groups may not only be due to spatial dependence induced by yet unmeasured environmental variables. From the Mantel correlogram it can be seen that for the first distance class in Nyungwe forest some positive spatial correlation exists (Fig. 3.4). At 0.016 to 3.42 km distance, most of the impact variables (e.g.: soil, precipitation, geology) are rather similar and thus autocorrelated which may be an explanation for the similarity in vegetation of the samples (Fig. 3.4). Nevertheless, while the general conditions are steady, some soil qualities, e.g. soil type, vary in a few cases whereas community membership of the sample is not affected. This circumstance might be a sign of local spatial correlation originating from community processes. Moreover, the abiotic impact variables are also correlated at a spatial scale broader than the respective sampling areas, the gradient depicted in Fig. 3.2 is what LEGENDRE & LEGENDRE (2012) called a “false gradient”. The same authors stated that such a spurious gradient may be generated by spatial process one of which is autocorrelation among the samples (IBID.). Nevertheless, there is a chance of unmeasured factors like soil moisture gradients or other variations in the soil finer than the sampling scale. Historical reasons, e.g., a landslide may still be reflected in the structure of the vegetation as well. Many of the samples from the same respective ranger station fall within the significant distance class and are part of the same species community. Many of the communities defined based on the clustering results consist of samples from the vicinity of the same respective ranger station. The samples which “skip” to another ranger station, i.e., are comprised in another plant community have to be reviewed individually. It might also be advisable to collect more data around the respective sample and evaluate if species composition changed and where the change may have occurred. This, entails recording the environmental parameters as well to elucidate if the change in species composition may be correlated.

As Šmilauer & Lepš (2014, p. 333) expressed, the interpretation of the spatial predictors chosen is inherently difficult. Only a vague notion of the relation between the increasing order of the predictors and their scale becoming finer exists, and further interpretation necessitates additional data recording. Furthermore, Legendre & Legendre (2012, p. 869) stated “that users should look for sets of MEM [PCO.n] eigenfunctions, corresponding to a given spatial scale, that, together, fit response data fairly well, not individual eigenfunctions.” Moreover, they warn “against the temptation to interpret a single MEM eigenfunction that happens to fit well a spatial structure that can be observed in response data”(ibid., see Šmilauer & Lepš, 2014, p. 333).

5.5 Reflection on the Methods

All of the methods used in this survey present one or the other disadvantage. In some cases, the concept and application of the family of methods is questioned altogether. In the following some pertinent issues will be outlined in the context of the current research subject.

5.5.1 Sampling and Establishment of Vegetation Units

It has been pointed out that the restriction in sample distribution and size led to undersampling. Additionally, the establishment of a minimum sample area in the dense and diverse vegetation proved time consuming and was not achieved in the end as can be seen from Figure 3.1. These hinderances made the correct application of the Braun-Blanquet system treacherous and in essence not viable. Species distribution and the, although discernible but gradual, changes in species combinations and patterns visible on site, leave some doubt to the strict application of the system anyway. These considerations and the observations made during data collection directly relate to a discussion that originated even before the term phytosociology was conceived and is persistently fought ever since on the merits or even validity of classification itself and its methods. This discussion will not be detailed here but some thoughts will be outlined that may be of interest to future research. The debate should also serve to justify the chosen approach and to briefly outline the advantages and the necessity of classification methods in the context of the survey at hand.

In 1988 Schmitz reviewed the vegetation units established until then for ZaÏre, Rwanda and Burundi. He remarks that the valid syntaxonomical units are still few. In the pretext Schmitz (1988) described that many surveys never classified the vegetation to the level of association. In the literature that was recent at the time, he critically noted a substantial fragmentation of vegetation units (ibid.). In his view many of the alliances established are rather sub-alliances and variants and many associations were synonymous. For the whole of ZaÏre (now D.R.C.), Rwanda and Burundi he accounted for 350 valid associations and 155 sub-associations. The few vegetation units of interest for the present study are in majority characterised by tree and shrub species, and only for a very few units species forming the herb layer are mentioned.[5] Certainly, underneath a closed canopy not much of an herb layer may develop, but many of the samples in the current survey give evidence to the opposite. As to provide a more comprehensive picture of the vegetation patterns, the survey at hand considers all of the species present in a specific site. From the critical observations of SCHMITZ (1988) and the vegetation patterns in the study area, the difficulties for an attempt at classification emerge. Hence, the question emanates: Should detail be sacrificed in order to keep vegetation fit into a system of abstract units or should an excessive number of units and their variants be evoked. In respect of the observations above, the question could also be formulated differently. Where are the borders of species communities if they exist?

According to WHITTAKER (1962, 1967), the question of where to cut the coenocline cannot be easily answered and in most cases entails arbitrary decisions. The visible change in species composition of stands along the coenocline takes place in relation to an environmental gradient and, according to WHITTAKER (1962, 1967), it is also a consequence of the reduction of competition between species at their distributional centres. Competition, on the other hand, can lead to communities more clearly delineated than the environment, as has been affirmed by BECKING (1957) and HANSON & CHURCHILL (1961), as cited in MCINTOSH, 1967). So, beyond GLEASON'S (1939) stochastic processes, environmental filtering sharpened by competition along with positive and negative interactions among plants within and across vegetation strata (BROOKER ET AL., 2008; CARDINALE, PALMER & COLLINS, 2002) constitute mechanisms of community assembly. These processes may not warrant a deterministic pathway for a so-called climax community to emerge, but are, also in combination with the local soil seed bank, serious obstacles, if not to the occurrence of single individuals, then to the establishment of a persisting population of a new species dispersed by chance, and therefore, to which species coexist at a specific site. Hence, the above mechanisms result in non-random plant assemblies.

Species distributions can therefore be described along a gradient at hand and the centres of distribution marked. Of course, the continuity in vegetation persists here, in terms of which WILMANNS (1998) described species to transcend the boundaries of their communities regularly and not even a species characteristic to one community is restricted to only the one vegetation unit it is characteristic of, it only shows an optimum in that unit. Accordingly, the broad overlap of species distribution curves may not allow for clear cut groups, but the spatial extent of and distance between said centres or optima of distribution may respectively be reasonably small and close enough under competition to describe observable patterns of informative value, even without immediately relating them to environmental gradients. At this point WHITTAKER (1962), who referred to SCHMID (1950), provided the option to classify stands as *types*. In the sense of WHITTAKER (1962) a *type* is a reference point in species hyperspace to which most stands are intermediate. In contemporary methodology like in FCM this notion could be referred to as a medoid. It has been elucidated that at least with the data at hand, a medoid, a *type* in the sense of WHITTAKER (1962) and SCHMID (1950) cannot be found. Fuzzy c-means, and in fact also the direct ordination methods used, offer the option to use centroids and are thus taking the notion of a *type* a bit further. If then, in accordance with SCHMID (1950), by using all species, or as WHITTAKER (1962) calls it "characteristics of whole communities [stands]", a group of samples is arranged around their centroid, i.e., their intermediate centre, an ecologically meaningful community (as an abstract type) can be conceived without shrouding the continuous change in stand composition (see SCHMID, 1950). Those "community-gestalts" should be developed in a number being sufficient to represent most of the range

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[5] Since not all of the literature cited by SCHMITZ (1988) could be obtained, the information on species composition rests mostly on SCHMITZ (IBID.).

of variation of communities in the surveyed area (Whittaker, 1962, p. 115).

A shortcoming of the survey at hand is that the number of different communities, though sufficient to permit the grouping of most stands around centroids, still leaves about 20 % of the samples devoid of a group centroid. Precisely because these more or less natural groups are not bounded classes and are characterised more by their centres than by their limits (Whittaker, 1962), the number of singletons leaves an unsatisfactory result. Then again, some of the singletons represent natural discontinuities and hence do not contradict the purpose to present the average or most probable stand properties at a given combination of environmental factors along the respective gradients and the relations of species distributions to one another (Whittaker, 1962). Given the outcome of the second FCM-NC undertaken on the communities established prior, the number of communities has been reduced, but it remains to be discussed whether the loss of information is acceptable and whether the average is still of explanatory power. It hence stands to reason that, depending on the desired level of detail, the supra-communities might be the actual basic vegetation unit. On the other hand, at this syntaxonomic level, the fit into the system of already described vegetation units was not improved either. The numbers equivalent of β-diversity of 37.90 based on species richness, as calculated according to Jost (2007), further supports the first exploratory result of cluster number as obtained by FCM-NC (see 3.2 and Annex 2).

Albeit the groups are not too distinct, the community structre as found by classification in the current study is also reflected by the ordination results. While unconstraint ordination detects species communities reasonably well, the methods lack the flexibility and clarity of the classification approaches used. Albeit the data and graphs derived via ordination allow for reasonable conjectures on vegetation resemblance, classification results lend themselves to a better interpretation in respect to species overlap and composition in general. Hence, classification by numerical and, as far as possible, objective methods can very well lead to results useful for environmental indication, utilising the information available from distributional relations of species and expressing environmental differentiation in detail (see Whittaker, 1966, p. 374). It should be mentioned that the group structure that can be derived from the ordination diagrams may possibly loose its separation even more when more samples fill the spatial gaps between them. The same loss of separation might occur among the clusters derived by FCM.

In order to attain abstract and relatively homogenous groups, objective statistical techniques like FCM provide most useful tools to achieve both a classification and the representation of continuous and intergrading change in species composition. If one craves a hierarchical classification method, the continuum still remains visible since the diversity measure used and the percentage information scales are continuous and therefore are representative of the gradual change. The arbitrary decisions on where to cut the tree are what finally introduces discontinuities. Here, the researcher decides on how many *types* with less favourable, less stable or less frequently realised species combinations remain between the clusters and when the abundance of defining species is no longer sufficient (Whittaker, 1962; see Wilmanns, 1998). Also, with the help of methods able to prune the tree dynamically, arbitrariness in decisions may be guided into better-informed paths. Moreover, since intermediates, i.e., ecotones or transition zones, in which slow and gradual changes eventually brought about by a changing environment may manifest, need to be detected and documented, numerical methods are of particular utility. Yet, in both the non-hierarchical and hierarchical approach vagueness remains in the definition of *types* (ibid.). It emerges from the above that there is no real dissent between the continuum approach and however arbitrarily defined vegetation units, at least not when one acts reasonable and targeted.

In order to obtain a realistic picture of the vegetation, subjective methods should not be used, especially not those that avoid ecotones as well as fragmentary and heterogeneous stands. This applies all the more to the vegetation in the study area, in which reiterating patterns are not as apparent as in a European beech forest, but are a rather patchy sequence of clearly different but only fuzzily separated communities, that can occur in a sigmoidal distribution. This reduction of the subjective and the inclusion of all stands facilitates the gaining of insights that are necessary in dealing with the current challenges. Moreover, by the use of objective methods and thereby the reduction of bias introduced by the researchers, comparisons among different areas can be facilitated.

In the light of the previous paragraphs, the results of HABIYAREME (1997) are to be seen critically. As it comes to HABIYAREME (1997), it is unknown to the current author how 800 m^2 plots were realised. Moreover, HABIYAREME (1997, p. 30) stated that he determined the plot size according to the site-specific factors underlying homogeneity of the vegetation types. Following that statement, he gave sample areas based on preconceived types (IBID.). Through this use of subjective and preferentially obtained data, the numerical classification method, which HABIYAREME (1997) used sparingly, loses its information value. The main part of HABIYAREME'S (ibid.) classification is created by the use of BRAUN-BLANQUET'S system. Although the preferential selection of samples benefits this system, i.e., the results obtained from it, the intermixture of differently sized plots within the analyses without any appropriate correction for it seems rather crude (IBID.). It seems almost certain that different communities were subsumed into one sample if not entirely then at least partly. At this point the reader may also be reminded of the choice of sample plot shape, in particular of the ratio of area to circumference and the resulting edge effects. This half-hearted approach can get in the way of credible results and can be an obstruction to finding relations between environment and vegetation.

On a further note, it was repeatedly mentioned that heterogeneity of the terrain and vegetation in the study area do not allow for large sample plots. This oberservation, made also by BOUXIN (1976, p. 97), would lead to the need to use differently sized plots to accommodate heterogeneities in nature. Other than in HABIYAREME'S (1997) case, who light-heartedly compared differently sized samples, the analyses would have to be emended either through the use of certain diversity measures or through resampling techniques and other randomisation procedures to obtain comparability.

In the conflict sphere between spatial resolution, the objectives of vegetation assessment, natural conditions and time constraints, solutions have to be sought that do justice to the framework of a study without renouncing ecological thinking in favour of statistical orthodoxy. A variable sampling design that meets the different requirements could be developed from the approach of POULSON ET AL. (2005). Although the settings and objectives of the work of POULSON ET AL. (2005) are not directly transferable, they offer an interesting approach in the above context and are therefore mentioned here. Moreover, their study is of particular interest because it is one of the few that explicitly considered the herb layer (IBID.). POULSON ET AL. (2005) used even larger sample plots but reduced the number of samples in their survey of forests of the Albertine Rift. While the sampling design used by the authors suited their study aims, it is still in disregard of the properties of the current study area. Moreover, the merits of POULSON'S ET AL. (2005) approach certainly include comparability and obtaining clear results that allow rapid assessment even of the herbal layer, but spatial resolution and resolution in terms of species composition and change therein are limited. Their nested design, however, modified and improved upon to suit the different needs outlined above, amended for the study site and purpose could be implemented in terms of a permanent, systematic monitoring array.

5.5.2 Spatial Autocorrelation (Pseudoreplication)

If one considers the direct surroundings of the respective ranger stations as a contiguous study area, the question of what is called pseudoreplication in manipulative studies arises due to the sometimes-small distance between the samples. Even if pseudoreplication is not the right term for non-manipulative studies, autocorrelation is a source of the same adverse effects (Šmilauer & Lepš, 2014). Oksanen, L. (2001) gives the right impetus here, scale. In the present study, we are dealing with an exploratory attempt to find correlations between environmental factors and vegetation composition at all scales. An appropriate resolution can only be found if all scales are taken into account. The partly small-scale vegetation and the diverse landscape profile would only be insufficiently recorded if the statistical independence of the samples were of the highest priority. Although the zone of influence determined by the Mantel correlogram is quite extensive, it only represents an average value under the given limited data situation. Furthermore, the distance class represents a range, up to which an influence can be inferred, that comprises all of the stands sampled and thus represents quite a variety of communities from diverse habitats and with different strategies. In addition, the results of the cluster analyses already show that the extent of this zone is not matched everywhere. With regard to the location of the sample sites, the respective distances show that a large part of the sites is located in the zone of influence of the respective nearest site, but this is not always reflected in the ecological distances, as can be seen from the Bray-Curtis values and the diastemogram (Fig. 3.3). The spatial proximity of the samples is also partly due to the small size of the forests. If replication were the priority here, the number of possible samples would be limited from the outset. In the case of Cyamudongo and Gishwati, the Mantel correlogram shows negative spatial correlation in a range substantially below the distances for Nyungwe. Here, however, the limitation of the small number of samples must be taken into account. This limitation, when considering the areas around the ranger stations as subplots, then also applies to the respective samples from these subplots.

In the dbMEM approaches, the scales on which spatial structures are found were shown and the variation was divided between spatial factors and environmental impacts. The influence of the autocorrelated data was thus limited to the part of the explained variation that includes the purely spatial structuring. The spatial variables representing the suspected autocorrelation were identified and discussed. As a result, the range of possible autocorrelation and thus pseudoreplication was assessed and the effects of spatial dependence were separated from the effects of dependence on environmental factors. This minimised the influence of autocorrelated data in the partitioning approaches. Considering the large Bray-Curtis values, the cluster analyses and the indirect ordinations, it is evident that the value for the zone of influence only gives a rough overview and is not equally valid for all sites. Until further data are available, the spatial correlation of the vegetation is tolerated because the goal of clarifying the causes of the vegetation distribution is in the foreground. The elucidation of the scales on which the vegetation varies and the individual factors act is not yet complete.

In future studies, the extent of the autocorrelation should be recorded as a function of the geographic direction, whereby systematic sampling is recommended. This takes into account the presumed irregularity of the zone of influence and facilitates the detection of boundaries between species communities, as well as opening up the use of methods in which spatial correlation is expressed.

5.5.3 Ordination and Variation Partitioning

Taking a look at the final variation partitioning approach comprising three groups of explanatory variables, the tb-RDA approach resulted in a higher explained variation. The most obvious source for the difference in explanatory power lies in the fact that more spatial predictors remained significant during the selection process, i.e., more explanatory variables more variation explained. Although, CCA should not have a problem detecting linear trends (Šmilauer & Lepš, 2014) and hence should be able to find the same correlations. Due to undersampling of course not all species were sampled evenly, i.e., some species optima were not sampled and hence some of the species distribution curves were truncated. Hence, the shortened curves and gradients covered may have led to the distortion of the gradient, due to biased estimates of species optima and the unequal distribution of weights on the truncated curve. This distortion then might, in turn, obstruct the uncovering of linear relationships. The number of curtailed gradients were maybe better detected by tb-RDA which does not utilise a weighting process. Beyond the fact that low percentages of explained variation impede graph interpretation, there are further elements that lead to low information yield from the graphs obtained by CCA. For instance, when the abundance curves had been truncated, rare species that occur in samples with low total abundances are placed at the end of the axes but have little influence. Hence, due to the axis ends that are compressed relative to the middle, a given separation distance in the ordination space does not bear a persistent meaning in respect to assumed differences between sampling units (Peck, 2010). Further information can be retrieved from Peck (2010) and McCune & Grace (2002) who gave a concise overview of the drawbacks of CCA (see also: Legendre & Legendre, 2012 and Zelený, 2021).

Since the distance preserved in RDA based on Hellinger transformed data is the Hellinger distance, the properties of the measure and the method, e.g., no weighting by species frequency, non-linear behaviour when approaching complete dissimilarity, may contribute to the better fit. However, it should be understood that the method when applied in this way only expresses the effects the environment has on the relative species abundances and changes therein. Especially when it comes to the fine scaled spatial predictors, RDA based approaches seem to better detect relations to vegetation patterns. The same seems to be true for some coarse scaled and medium scaled predictors (see paragraphs 4.2.5.2 and 4.2.5.3).

Examining the partitioning results leads to the realisation that the percentages explained by the different partitions vary considerably. While the environmental variables alone only account for 2.4% tested for conditional effects and lost statistical significance at the same time in CCA, they account for 6.2% in the tb-RDA approach. The difference becomes more evident considering the share of the variables in the variation explained (Tabs. 4.30 & 4.31). The contrast can be seen most strikingly in section g, the fraction which is jointly explained by all three groups of explanatory variables. There are several options that have to be considered here. Starting again with precipitation, elevation a.s.l, forest matrix and position to the watershed, tb-RDA results in almost three times the explanatory power of the pure environmental factors than CCA. Looking at the results from CCA, most of the variation explained in species composition stems from the fact that the environmental variables are spatially structured and from the overlap with the soil properties. In CCA, this results in the loss of statistical significance of the sole environmental impact. Despite the fact that tb-RDA likewise elucidates the spatially structured elements of the impact variables, still the residuals of the respective gradients seem to be of explanatory value. Set into ecological terms it could be said that given similar conditions pertaining to elevation a.s.l., precipitation, distance from the forest edge, forest matrix and watershed position, the soil conditions as given in (Tabs. 4.30 & 4.31) exert the main environmental control. In addition, the tb-RDA approach suggests that still some impact of the environmental variables sensu First Group (Tab. 4.30) is measurable.

While the dropping out of the distance to the forest edge in the final variation partitioning approaches may cause some disbelief, it should be kept in mind that not only is the distance correlated to many of the impact variables, but that it presents a spatial structure in itself. Thus, the inclusion of spatial predictors did not increase the unique contribution of the distance itself. Here, the conclusions of Cadenasso et al. (1997) regarding the different ranges and effects of the respective factors could be relevant.

When it comes to the impact of the soil parameters, both approaches detected the spatial structuring of the respective properties. While CCA resulted in the largest share of variation explained by soil parameters alone, tb-RDA produced a similar share in total explanatory power but yet the largest contribution stems from the overlap of all three groups of variables. Thus, albeit soil parameters have been recognised as impact variables (Habiyaremye, 1997; see 3.2.5), it seems that beyond being influential in otherwise commensurate conditions they impact species composition not only in a joint manner with climatic factors but on their own and to a far greater extent than previously reconned. Looking back to the partial ordination approaches, the [C]:[N] ratio often contributed most to the explanatory value. As we have seen, attention is in order when establishing unidirectional causation between said ratio and species composition.

Despite both being negligible, the solely spatial fraction obtained by variation partitioning via tb-RDA is in absolute terms almost double than what resulted from CCA. As has been mentioned before, the reason may be found in the merely higher number of spatial predictors. If this is also the case for the joint effect of the explanatory variables, i.e., fractions e, f and g or if tb-RDA better related the variables to one another or if by using CCA a better resolution was achieved certainly requires more field work. The loss of significance of the purely spatial fraction in CCA might also be a symptom of undersampling and the effects resulting from it.

Considering the suite of explanatory variables, both methods roughly give the same results. Evaluating the conditional effects mode first, differences can be noticed in the second group comprising the soil parameters. While the limitation of the drillable soil depth by stone, which in this case approximates the rooting depth, remained of significance in the linear method it seems of no importance in the unimodal one. Both methods are in agreement when it comes to the impact of the [Mg]:[Al] ratio but only CCA considers the [Ca]:[Al] ratio likewise as important. In this context, one should recall that in the CCA based approach, two samples with unusually high values in said ratio were removed prior to the analyses. The importance of the [Al] with respect to the availability and concentrations of Magnesium and Calcium was already recognised by Habiyaremye (1997, p. 88) in a rather pragmatic way. The final forward selection using CCA results in a loss of statistical significance of the [Mg]:[Al] ratio during the process. This does not come as a surprise though, since this ratio never constantly remained of statistical significance and is correlated to pH. Here again the removal of the two samples exhibiting elevated values in this ratio has to be kept in mind. The test of the simple effects in the tb-RDA procedure resulted in a loss of explanatory power of the limitation of the drillable soil depth. Here, a reason might be found in the collinearity of the factor to variables selected prior in the interactive forward selection procedure. While the set of variables got more parsimonious for the soil factors, the array of spatial predictors grew by a total of three whereby one descriptor dropped out of the original set. A reasonable explanation is proving difficult. It has been stated that some of the contiguous predictors model similar trends and that interpretation is deemed inherently difficult. Hence, the evaluation of the patterns described by the predictors and the relations to the species data is beyond the limits of the current survey.

With regard to the sample sites that are significant in LCBD, the samples that are conspicuous outlier or remained singletons during classification, the specifics of the environmental parameters are thus reflected by specifics in the species composition. Whether it is only the factors, undoubtedly interacting, whose importance was highlighted in the ordination analyses, that impact the vegetation is doubtful. A probable element in the series of impact variables is certainly the lack of exchange between the floras of the individual forests. According to Fischer & Hinkel (1993), the isolation of Cyamudogo Forest has existed for more than a hundred years.

Soil conditions are based on complex interactions between the impact factors, these leave open the question of the origin of the sometimes extremely high measured values of [Ca]:[Al] and the increased values in [Mg]:[Al] in the samples. It is not possible to determine whether these are due to errors in the analysis or whether, despite pooling of the samples, a distortion occurred during sampling. Further sampling would be required to fully elucidate the interrelations.

5.5.4 Interim Conclusion

In result, the analyses conducted have mainly brought out the structure of the ranger stations, i.e., the differences among the individual sites from around different ranger stations. This is not surprising, as the results of the cluster analyses already show that the majority of the samples grouped together come from the vicinity of the same station. The Mantel correlogram clearly shows significant spatial correlation for the first distance class. The resulting influence zone of 0.016 - 3.42 km for Nyungwe forest (see Tab. 3.4), which, if one considers the matrix of geographical distances, applies to most of the samples from the vicinity of a ranger station. However, it can also be stated purely empirically that some vegetation units show a zone of influence at the lower limit of the given range. For the cases of Gishwati and Cyamudongo, such conclusions can also be drawn directly from the Mantel correlograms. Also from observation, it can be determined that in many cases the causes lie in past events or in soil conditions. It can also be seen from the results that not all of the variation in species composition is generated by the effects integrated by the identity of the ranger posts.

What was achieved beyond recovering the structure of the ranger stations and confirming the spatial structuring of the environmental variables, is the illustration of the impact of so-far ignored factors. Beyond the quantification of the impact of the independent variables, it was found that some of the soil factors, besides being affected by climate, have considerable effects on their own. Although Habiyaremye (1997) already realised the impact of soil variables, he only indirectly related them to the plant communities encountered by him. The author used the same indirect approach in all the analyses he conducted (ibid.).

In the current study, direct relationships between environmental factors and vegetation data were established and concretised by partitioning the explainable portion of the variation in the species data to the respective impact parameters. Furthermore, the not new finding was confirmed that the impact factors do not act independently of each other. They influence each other and thus also manifest their effects indirectly, e.g., climate conditions are mediated through the soil. The variation in importance of the effect of the independent variables takes of course no wonder. In some cases, however, it requires further field work to evaluate if a variable has an impact in the real world. For instance, it would be necessary to assess whether only the geographical distribution of the samples close to roads was discovered or whether there are measurable impacts.

The general tendencies are well depicted by the ordinations, with an apparent advantage of tb-RDA and db-RDA. Both methods better differentiate between samples and seem to better pick up spatial variation at the pertinent scales. Although the general percentage of variation explained is reasonable, the individual fractions are low. Hence, when it comes to inferences from the graphs for the individual samples, erroneous judgments are most likely (ter Braak & Šmilauer, 2012, p. 228). Thus, the recorded and measured variables must be consulted which counteracts the intention of ordination to simplify the process of identifying the drivers of variation in species composition. Some of these supposed drivers exhibit quite some collinearity, i.e., multicollinearity. A fact which is illustrated by the variance inflation factors (VIF), the adjusted P values and the correlations among the impact factors. Some of the relations are real, for instance the one between elevation and [C]:[N], some are supposedly spurious due to the sampling design. During the (partial) canonical analyses a reduction in the VIFs was achieved and in some cases collinearity was eliminated. Therefore, the above-mentioned problem of interpretation was fairly mitigated and the number of possible origins of the variation in species data has been limited.

Beyond exemplifying the usefulness of preferentially obtained data in the large-scale representation of relationships between diversity and its drivers (see: Roleček et al., 2007), it was possible to give an impression of beta-diversity itself. While discrete numbers give a general expression of diversity by means of various diversity indices, specific samples could be determined via the LCBD, which are distinguished by their species combination (see: Michalcová et al. (2011). Here, the results are in concordance with the clusters derived by means of FCM-NC, which in turn also give shape to the continuous proportion of this diversity as it is found in reality. The samples with a particular contribution to diversity are evident in all the methods used and are not are mere artifact of undersampling, but represent natural discontinuities and samples of distinctive species combinations.

5.5.5 Caveats and Recommendations

When it comes to the results of this survey, their rather tentative nature is obvious. Severe undersampling in both sample size and number does not allow for any incontestable conclusions that lead to factual causations. The same undersampling is the basis to some at the first glance rather arbitrary and haphazard decisions. The conjectures put forward here nonetheless allow some interesting conclusions to be drawn and offer insights into relations that have not previously been described and quantified in connection with species communities. Nevertheless, these should be interpreted with caution and some points will be given here that have to be considered.

The modus operandi pertaining to the choice of sample sites and their size has been laid out in the chapter detailing the methods and under point 5.5.1. Although from a pale theoretician's vantage point, the ultima ratio total randomness does not tolerate any dissent, reality often repudiates it. Dealing with a small-scale environment in an equatorial latitude brings about the necessity of on-the-spot decisions and a time-efficient sampling design. In other words, a randomised design, stratified or not, is not suitable in a landscape of steep slopes and severe erosion paired with rather short daylight hours.

Another much moot point is the size of a plot. The plot size chosen for the analyses at hand is, in general, not suitable for vegetation surveys in closed canopy forests; thus, sometimes a single tree dominates the plot, and the diversity of the area could be underestimated as a result. Furthermore, false inferences about species composition can be made and the establishment of species communities is made an arduous task. For instance, the distribution of a species or in fact a species community can take the form of a sine wave. This sinusoidal pattern then may lead to a contrasting species interspersed in an otherwise homogeneous e.g., canopy layer, and thus, increasing the dissimilarity of the respective site and falsely setting it apart from the other sites. As follows, the many noise samples and the singletons obtained by classification may not only be evidence of the high biodiversity they might as well be a sign of undersampling. Therefore, the results are to be taken with quite a grain of salt. Another angle in this consideration are the mass stands of certain species which can occur in different habitats. In the present study, barely a site was set apart for that reason. The question here is, do these stands form a variant of a community or are they just intermediate states which come to an end after e.g., a mass blooming or are they in sequence with such mass blooming events, i.e., do the recur every few years. The stands dominated by *Mimulopsis excellens* clearly demonstrate that such patterns can be formative of a plant community.

Then again, if the plot size is chosen to be larger, will the mass occurrence be diluted and just become another species with an increased abundance? The same may be said in respect to the afore mentioned noise samples and singletons. Are these just points in space where species composition differs due to a single dominating species in the canopy layer along with some differences in the lower strata or is it just the edge of an assembly that differs widely in species composition and extends further in geographical space? It has been pointed out under 5.5.1 that these questions apply to about 20% of the samples, i.e., those that could not be grouped around a centroid. In order to determine whether a singleton is the result of undersampling or represents a natural discontinuity, a systematic and nested sampling design, although laborious to set up, seems the most useful choice.

Fortunately for the phytosociologist the dogma of "no two trees in close proximity to each other are of the same species in a tropical forest" does not hold in the survey area. This makes classification a bit easier and facilitates inferences about relations between environmental factors and species composition. On the other hand, in the vegetation strata below the canopy, change is rather without obvious patterns. This circumstance renders respective classification results only a rough depiction whose precision depends on the resolution of the frame of reference. Thus, should the differences in species composition within these lower strata be amalgamated into a more comprehensive and heterogenous unit or should attention be paid to detail? This may become an important question to ask in the face of species range shifts due to a changing climate.

From the above and the preceding considerations (5.5.1), it is clear that the plot sizes to be applied according to customary practice for forest stands are not suitable under the given conditions to effectively obtain data that can be processed in an efficient manner. In the present study the problem is not necessarily one of a too small plot size but of a plot density not representative of the vegetation patches. Still, ecotones were registered as well as edaphic communities without the sample plots being specifically placed for this purpose.

In essence, smaller and denser samples allow for a higher resolution and the detection of change in species composition without sacrificing spatial scales from the outset. The most informative results should be achieved through a systematic and nested sampling design. The spatial dependence (pseudo-replication) present in data thus derived can be separated from the environmental dependence of species data by today's methods. Moreover, the range of spatial autocorrelation can be determined and permutation methods exist to accommodate the spatial sampling design of systematic sampling grids and transects. Hence, the impacts of the proximity of the sample sites can be accounted for. In combination with (spatial contiguity constraint) FCM-NC, fairly reliable communities and their spatial extent can be delineated and continuities in the vegetation be depicted. Finding the boundaries between communities in geographical space can also be achieved based on dedicated numerical methods. Here, the interested reader is referred to the works of ODEN, SOKAL, FORTIN & GOEBL (1993), FORTIN & DRAPEAU (1995) and FORTIN, DRAPEAU & JACQUEZ (1996). Unfortunately, undersampling prevented the application of the methods detailed by the afore authors as well as spatially constrained clustering approaches.

Especially when the classification of stands is not an end in itself, but a reference to environmental parameters is to be established and changes in stands are to be observed, a more detailed data record seems appropriate. Considering the relevance of the time factor and perhaps the monetary component of field research, sample plots of 200 m^2 should be possible if all of the species present are to be considered.

The reduction but not suspension of subjectivity through the critical use of objective methods is a means to achieve an essential depiction of the main characteristics of vegetation composition by efficiently using the largest part of information contained in the distributional relations of species. In this approach, part of the way towards a better understanding of the whole can be covered and insights into the complex relationships between environment and vegetation patterns can be gained through characteristics or composition of communities and their changes.

Up until here a point has been made towards the reflected application of numerical methods in the classification of vegetation whereby utilising most of the information accessible in the vegetation data. It is pointed out here again that a unified approach should be used to be able to compare similar vegetation from other areas. The resulting difficulties in attaining such databases have already been described by SCHMITZ (1988). Another consideration that has already been mentioned concerns the fact that many of the species of conservation relevance can be found in the understory. Hence, it would be appropriate to categorise the variants of the communities more precisely, i.e., more restrictively, at the local level. When utilising numerical methods, communities can always be consolidated where necessary and appropriate. This community concept, which is at least locally more flexible, could be an instrument to cope with the at times wildly fluctuating species composition in the understorey. This practice in combination with the sampling design mentioned would be of advantage in the monitoring of species populations, especially of rare species, and should compensate for the initial additional effort.

At the end of the day, classifications should be seen as a means to describe vegetation in order to be able to recognise alterations in species composition and distribution. Numerical methods, such as fuzzy c-means with noise clustering do not disregard the continuum concept and still allow for a classification giving a reasonable impression of the vegetation, its structure and patterns. A dendrogram derived by whichever hierarchical method still does provide an overview on the vegetation which can be retraced in nature. To obtain a picture as close to reality as possible, quantitative data should be employed since incidence-based data does obscure important parts of the information contained in vegetation data. The majority of surveys rely mainly on the distribution and joint occurrence of trees to draw conclusions from. However, through this approach, essential parts of the information contained in the vegetation patterns are lost. Hence, vegetation in vivo should only be contemplated as a whole. This is especially true in an ecosystem whose inherent mechanisms of maintaining a tremendous species richness are still not fully understood. Here, a way has to be found to account for small scale variability and rare species without obtaining an incomplete picture. While POULSON ET AL. (2005) were mainly concerned with large scale comparisons, their nested concept in an improved and adjusted version would be a promising basis.

Another point arises from the collinearity (as evidence by the VIFs) between some forest matrix states and some ranger posts as well as the distance to the forest edge. Naturally a correlation will be found between the ranger post and the surrounding type of buffer zone because of the close proximity of the sample sites to the starting point and the often large spatial extend of the kind of buffer zone. Hence, in future surveys the effect of the position towards the respective ranger station should be partialled out before further analyses. In this respect it should as well be of merit to collect data from sites further away from the edge and spread out along the respective forest matrix. Thus, false inferences due to spurious correlations could be reduced and more reliable conclusions could be drawn on the relations between forest matrix and species composition. The same applies in more general terms to all the independent variables that have been found to have an impact. Therefore, if the remaining impact factors truly impact plant composition necessitates further field work and adapted sampling designs to directly target the impact factor chosen. In the ensuing analyses a way has to be found to use the states of factor variables independently without converting them into dummy variables. For now, the necessary inclusion of complete factor variables in variation partitioning procedures (re-)introduces a high degree of multicollinearity and obscures the impact of single factor levels.

As a further exhortation, the forests should be analysed on their own. The spatial predictors also cover the large distance from Gishwati to Nyungwe and thus are partly “wasted”, i.e., are not available to model finer structures. To the same end, clustering with spatial constraint would give more precise delineations of species communities. Even more explicit spatial conclusions could be achieved by applying different connectivity matrices and weighting the established links. Eventually, disconnected sites should be modelled separately. Again, undersampling prevented the separate analyses of the forests and the application of more explicit analyses in the current study. The same is true for the Mantel correlograms computed for section 3.1. It is apparent from the clustering results that the given range of influence does not apply to all of the stands. Another aspect to be considered is the omnidirectional nature of the correlation illustrated. Refinement can again only be obtained if it is informed by a wider database. Moreover, the negative correlations resulting for

Gishwati and Cyamudongo Forests may also be the product of an insufficient number of samples. Hence, the results provide only a general idea in both extent and geographical direction.

A further deficiency arises from the low setting of the fuzziness exponent m in the FCM-NC analyses. Since the "strange number" m (Bezdek, 1981) could only be set to 1.2, the memberships given, other than the primary one, are very low and could only be taken as pointer to cognate communities and membership probabilities.

Another caveat stems from the unequal distribution of samples between the eastern and western side of the watershed. Due to the lack of accessibility a more balanced design may be difficult to achieve but should be strived for. The inclusion of samples along the so-called watershed trail in Nyungwe Forest is a feasible endeavour for that purpose. Since there is a quite high proportion of unexplained variability, impacts of so far untested environmental factors are highly likely. Among those, impacts of past anthropogenic exploitation constitute an interesting but certainly not easy to evaluate factor, as well as the essential effect of soil moisture, which can and should be studied directly. On a final recommendation, epiphytes should be sampled in future surveys since they are sensitive indicators of environmental change and anthropogenic impacts.

5.5.6 A wider View and Perspectives

It has been shown in the current survey that small areas can make a substantial contribution to diversity. It is even possible, as is shown by Cyamudongo and Nyungwe Forests, that two areas in spatial proximity can be vastly different in species composition, and that some of the species may be exclusive to small forests like the new *Carapa* species present in Cyamudongo. Albeit commonalities among Gishwati and Nyungwe as well as Cyamudongo are more frequent, still 57% of the species found in Gishwati Forest are exclusive to it. Since edge effects not only directly impact tree mortality, species turnover, recruitment and competition among species of different habitat types, but fragmentation also results in indirect effects via impeded seed dispersal and a possible increase in herbivore pressure, the persistence of species populations in small forest stands like Gishwati or Cyamudongo is fraught with doubt (Köhler, 2000; Laurance et al., 1998; da Silva & Tabarelli, 2000; Law & Lean, 1999; Kupsch et al., 2019). Moreover, Kahindo, Bowie & Bates, (2007) pointed out that beyond mere species diversity genetic differentiation in isolated forests may have important implications for conservation planning as well. Hence, future research and management should consider to increase the attention paid to small forest stands. From the considerations under 5.5 it becomes clear that edge effects might be especially harmful to small forest fragments especially when these are of irregular shape (see Laurance et al., 1998). A step in the right direction has been undertaken by the Rwandan government by protecting Gishwati and Mukura Forests irrespective of their state of disturbance. Outside of protected areas though, degradation of the few forest remnants left is of major concern. In this context, Ndayisaba et al. (2016) attested that different forest types are severely endangered, and Kayiranga et al. (2016) verified and quantified not only the ongoing degradation of forest cover outside the Nyungwe-Kibira Park area, but also within the park boundaries. Anthropogenically accelerated degradation can cause further problems like Senyanzobe, Mulei, Bizuru & Nsengimuremyi (2020) have shown for the excessive proliferation of *Pteridium aquilinum*. Evidently, the impacts of historical and recent anthropogenic activities and the development of thus degraded vegetation are worthwhile research subjects, here as well as in

Nyungwe Forest.

Beyond species and habitat loss, the consequences for the carbon sequestration capacity are linked to forest degradation as well. Nyirambangutse et al. (2017) stated on this background that carbon sequestration was on average higher in late successional forest stages. Nsabimana et al. (2008) conducted research on the sequestration capacity of different tree plantations. Their results showed that the potential to sequester carbon varied greatly depending on tree species, soil type, climate and management (ibid.). Nsabimana's et al. (2008) work leads directly to the impact of the forest matrix. In the current study some forms of matrix were of clear impact, among which were the buffer zones consisting of trees and the ones containing roads (see 4.2.5). The impacts of roads and other open matrices may contribute to forest degradation (Nyandwi, 2008; Laurance, 1998). Beyond the well-known point of the impact on local microclimate, tree plantations seem to have an impact on soil processes and nutrient availability (Nsabimana et al., 2008). Here, Cizungu et al. (2014) pointed out that underneath a *Eucalytus* plantation nutrient depletion in the long term is highly likely. This raises the question of the spatial extent of the depletion zone and its possible impact if not directly on the adjacent natural vegetation, then on what will and can be planted subsequently.

The overview of the vegetation patterns in respect to the environmental features surveyed in the current study provides some detail on the respective relations, and the main drivers of diversity have been quantified. It was shown that soil conditions impact species composition to a previously unknown extent. So it seems, for example, that the soil conditions contribute to quite some extent to the underlying drivers of the vastly different vegetation composition of Cyamudongo forest. It has also been pointed out that species adapted to the climate at high altitudes impact soil conditions via the composition of their leaf litter. This adaptation is a circumstance that may under changing climate conditions lead to a total change of vegetation. This is because not just tropical forests in general may be at their photosynthetic temperature limit (Doughty et al., (2008), but tropical montane forests could be particularly so (Dusenge et al., 2015). It also stands to reason that elevated [CO_2] will negate the harmful effects of a temperature increase (Doughty et al. 2008). Vårhammer et al. (2015) pointed in the same direction suggesting that especially climax species will be negatively impacted by increasing temperatures. It emerges from their conclusions that warmer temperatures may imperil seedling growth and recruitment and that migration and survival rates of climax species could as well be negatively impacted (ibid.). Furthermore, not only canopy species may be affected, but co-occuring biota which may not be able to persist in non-climax vegetation communities (ibid., see Poulsen et al., 2011) The authors further suggested that different species that grow together may have similar responses but they may also experience different stress levels (Vårhammer et al., 2015). On a further note, they reminded of the competitive balance among tropical plant species which might be altered due to differences in plant traits and hence responses to global warming (ibid.). It was pointed out earlier (see 4.5.5) that increased temperatures will also impact litter decay and mineralisation at higher altitudes. Hence, the adaptation of species to high altitude nutrient cycles could turn into a competitive disadvantage and may lead to the replacement of high-altitude species by warm adapted species that may outcompete them. Seimon & Picton Phillips (2012a) specified an upward displacement of vegetation in an order of 600 - 720 m considering an average increase in temperature of 3.6°C. The same authors (2012b) raise the issue that with temperature increase also the long-term sustainability of tea plantations is in doubt.

These possible, imminent changes in the environment justify the study of species communities because their ensuing changes in composition can provide information on the degree and severity of ecosystem change. Apart from the fact that GLEASON (1939, cf. WHITTAKER, 1972) wrote about time periods inconceivable on a human scale, a plant communitiy may well be seen as an ephemeral construct, but still the reasons why it changes are of interest, especially in times where change is man-made. Therefore, the status quo and likely change of the, however temporary, species communities should now be recorded in suitable permanent plots comprising all pertinent environmental and soil variables.

Overall, it has been shown that environmental variables are spatially structured and that the main part of the vegetation patterns can be related to the structural components. In other words, it is apparent that the spatially structured components mark pronounced differences in habitat traits and if those change the plant communities, despite the different species responses, maybe be threatened to vanish over time because the species constituting the community are by and large adapted to the same (for other species) adverse environmental conditions. Hence, native autochthone species may fade and be replaced by generalist species. In the big picture, the multitude of interdependencies and challenges begs the question if the vegetation distribution, or even species diversity, are persistent in environmental change and can be maintained.

From these brief highlights of the results and their implications, the question arises under which conditions the existing level of protection can be maintained and improved. The most obvious challenge is the demographic pressure on the natural resources. The 1.5 Mio. inhabitants that led VON MECKLENBURG (1909) to deem the than larger Rwanda a densely populated area have grown to 13 million. Most of the population inhabits rural areas and according to MASOZERA, ALAVALAPATI (2004), it is the younger households that depend more on forest resources. The two most salient issues are that most of the energy needed in Rwandan households is generated from fuel wood and that most of the population depends on subsistence agriculture. Deforestation decreased widely due to conservation measures but it does not divert attention from the fact that most parts of the country are already deforested and forest degradation still is of concern (KAYIRANGA ET AL., 2016). Under these circumstances, conclusions from the natural sciences can only be successfully applied if areas outside their expertise also create a conducive framework for their implementation. Therefore, we will have a quick look at the developments.

In recent years many a study has concluded that alternative sources of income have to be generated, access to cross-regional markets has to be provided, benefits have to be distributed equally and incentives be created to use other than forest resources (MASOZERA & ALAVALAPATI, 2004; LEONE, 2015; CRAWFORD, 2012; UMUZIRANENGE & MUHIRWA, 2017; RUTEBUKA ET AL. 2010). One of the means listed by LEONE (2015) to achieve a diversified job marked and take pressure off of natural resources is agroforestry (see MASOZERA & ALAVALAPATI, 2004). This approach is still in its early stages and discussions of tree species and crops to use are ongoing. Although a considerable number of native species are in use, exotic species are still widely accepted. Here, and the same is true for tree plantations, also environmental implications arising from the tree species planted must be considered. NDAYAMBAJE (2002), MASOZERA (2004), CIZUNGU ET AL. (2014) and GAPUSI (2007) provided valuable advice with regard to plantation management, the intensity of use of the various species by the population, and the impact of various exotic species on the ecosystem. NSABIMANA ET AL. (2008) advised reforestation with increased use of native species, especially with regard to soil quality and CO_2 sequestration.

A major agroforestry project is currently carried out by the Rwanda-Centre at the University of Koblenz-Landau around Cyamudongo Forest. Here, mainly native tree species are used to foster biodiversity, enhance soil and habitat quality, and create a sustainable semi-natural buffer zone, while exploring the utility of native trees and promoting this concept amongst the population.

Tourism is widely regarded as a tool to generate alternative income. Here, Rwanda quickly accommodated for the two faces of this industry by implementing a pricing policy firming under boutique tourism to controll visitor numbers. Hither, the survey of Lal et al. (2017) pointed to some pitfalls of this policy in terms of willingness to pay and equality of access especially for parts of the local population. This high-price practice might also backfire since the willingness to pay for conservation might be put to the test by very low-standard services (Munanura, Tumwesigye, Sabuhoro, Mariza & Rugerinyange, 2017). Furthermore, education efforts in terms of acceptance of conservation measures and of ecosystem services provided by an intact forest have been promoted as well as compensation for crop raiding by forest fauna (Umuziranenge & Muhirwa, 2017). In general, there was a call for the participation of the local public in every respect (e.g., Masozera et al., 2006; Umuziranenge & Muhirwa, 2017).

Said demand was put forward particularly in conjunction with the participation in the economic benefits of the different buffer-zone management types. A challenge that still exists is the unequal distribution and application of the opportunities listed. Here, Leone's (2015) demand for a landscape approach should be implemented urgently. Crawford's (2012) proposal to map hot spots throughout the buffer zone in order to concentrate conservation measures is a starting point, because forest resources are used more often where there is a lack of alternatives. Leone (2015) further warns against the commoditisation of nature and the separate marketing of ecosystem services. As to prevent the exclusion of the local population from economic benefits generated from buffer zone cultivation, he further cautions against alliances with private companies (ibid.). This problem has also been identified by Gross-Camp, Martin, McGuire & Kebede (2015), who asserted increased difficulties in buffer zone access by the local population. Gapusi (2007) realised as well that mostly foreign companies benefit from the buffer zones but identified another drawback in the loss of farm land by the conversion to buffer zone. Acceptance of these conversions is not fostered by the fact that access to the tree plantations is officially not allowed (pers. comm., Seidel, 2020)

So, from being hostile to the point of being almost uncontacted, to being inviting to neo liberal privatisation (Gross-Camp et al., 2015) at the risk of excluding the native people, Rwanda has come a long way. The challenges to be taken on range from mere sustenance of the local population to their education and participation, to equal distribution of economic benefits. The control and viability of tourism has to be worked on (see Munanura et al., 2017; Lal et al. 2017), buffer zone management has to be transformed in a way to avoid conflict and attain equitability, tree plantations and agroforestry have to be implemented to avoid adverse effects on the ecosystem and benefit the local population (see Gapusi, 2007; Leone, 2015).

Progress can be seen in legislation where compensation for crop raiding and injuries caused by wild life has been implemented (NewTimes, 2011; MINICOM, 2011, 2012). When it comes to agroforestry, implementation is slow. As a result, the ancillary sector is also developing poorly. For now, one person is selling saplings and fruits (pers. comm., Seidel, 2020). Cooperatives like those found in beekeeping do not exist here. The suggestions to drain wetlands for agricultural purposes and allow agriculture in protected areas where it was already present put forward by SORG (1978) and GILAROWSKY (2000) respectively, have luckily not been put into action. Meanwhile a rehabilitation program for wet lands was implemented (pers. comm. SEIDEL, 2020). The discontinuity in the relationship between the people and the government criticized by MASOZERA, ALAVALAPATI, JACOBSON & SHRESTHA (2006) may exist in the naming of the authorities and in part their jurisdictions, but in terms of staffing and responsibility, continuity is provided (pers. comm. SEIDEL, 2020). It remains to be seen whether the efforts of industrialisation, state-imposed cultivation in forced cooperatives and large-scale land holdings in a country with chronic energy shortages, in which 70% of the population live largely from subsistence farming, are conducive to the efforts of species conservation and environmental protection.

According to its National Report on the Convention on Biological Diversity, Rwanda is well on its way to achieve the 2020 targets set by the Rwandan Government (REPUBLIC OF RWANDA, 2020). At 9.13%, most of the 10.3% of national territory holding particular biodiversity envisaged to be safeguarded by 2020 is protected (REPUBLIC OF RWANDA, 2016, 2020). If conservation can be enforced in light of the problems outlined above, lies in the future. Among the diversified 19 goals set for 2040 by the Rwandan administration are mainstreaming of decision making in biodiversity conservation and the establishment of corridors and connectivity between fragmented habitats (esp. Gishwati, Mukura and Nyungwe) and extension of protected areas where possible (REPUBLIC OF RWANDA, 2016, 2020). It is to be sincerely desired that these aspirational goals, whose main concerns can be summed up in the integration of environmental protection and equality in economic prosperity, will be achieved.

6 General conclusions

As one of the first quantitative surveys in the area, the study established spatially explicit relationships between vegetation communities and environmental parameters. It could be shown that the 1198 species that could be distinguished within the 94 samples collected in the survey, form continuously merging but nevertheless distinguishable species communities. Correlation analyses by Mantel correlogram resulted in an average zone of influence for a stand of 0.016 to 3.42 km, i.e., an average community size in Nyungwe Forest. By the application of two different numerical classification methods, FCM-NC and UPGMA, a community structure was elucidated in which 20 to 40 different species combinations can be identified, depending on the level of detail required. Although the fifty percent share of singletons in each case is a clear indication that the sample size is too small, some of these communities are located at natural habitat boundaries and at transitions between the centres of distribution of their constituent species. Thus, even in the limited sample size, indications of natural features in species distribution and composition in the continuous species assemblage could be found. The highlighted patterns in species distribution are predominantly determined by the commonly known impact factors. This is linked to the importance of the spatial structure of these parameters, i.e., the different characteristics of the environmental parameters in the individual forests and parts of forests. The role of selected soil factors whose impact has so far only been marginally considered has been quantified and shows a higher degree of importance than previously assumed. Strong indications of the impact of some states of the forest matrix were also found. Also, the distance to the forest edge seems to affect species composition. Here, the survey reaches its limits due to the restricted possibility to get to a further distance from the edge in general and especially without a marked change of elevation. Hence, due to insufficient sampling the suspicions cannot be substantiated into a causal relationship. The differences of Cyamudongo Forest in terms of species composition can be derived from climatic and soil factors. However, this first insight is not sufficient to fully explain the causes of the wide-ranging differences. Under the given conditions, the proportion of explainable variation in the species composition of the forests lies between 21.7% and 37.8%. The majority can be explained by the spatially structured fraction of the impact factors. While on the broad scale climatic factors, the altitude above sea level and the geology are determining factors, some soil parameters and matrix components also show their impacts here. In the mid-range of the scale, it is the forest matrix, the soil types and the geology that determine species distribution. While in the fine range of the scale some unrecorded parameters seem to have an effect, there are also neutral processes that determine species composition. The spatially structured fractions of these parameters account for between 30.5% and 49.8% of the explained variation (100%). The purely environmental parameters account for a share of 10.3% to 16.3%, whereby the lower limit originates from the unimodal approach and has lost its statistical significance. The soil variables, also after partial analysis, account for a share of 19.0% to 35.7%. Beta-Diversity when expressed in numerical form resulted in an average Bray-Curtis dissimilarity of 0.92. Expressed in JOST'S (2007) numbers equivalents 37.90 equally likely samples would be needed to obtain the diversity found considering the impact of rare species. Given the rarefaction estimates of species richness, diversity is rather underestimated by the above measures.

The necessity of habitat protection can be directly deduced from the results. Here, it is the move towards a qualitative approach to species conservation that must be pursued. It is beside the point to prioritise by quantity what little has been left since every loss of habitat entails a potential loss of rare species. Moreover, ecosystem services, whose maintenance is aimed at, depend also in the spatial extent of an intact ecosystem. Hence, all must be protected under the imperative consideration of anthropogenic interferences and in a spatially explicit landscape approach.

Furthermore, phytosociological studies are a necessity to detect and cope with species distributional and compositional changes in the wake of environmental change. In this context, the different aspects of statistical methods should be used in a complementary way to attain as informative as possible a representation of the interrelationships between vegetation and environment. Here, the critical use of numerical methods should not serve to exclude subjective judgement, but rather to avoid arbitrary decisions and the associated distortions. This serves the purpose of a general and supra-regional comparability of research results. The high beta diversity renders the task to assess the vegetation as a whole laborious, but species distribution patterns in tropical vegetation necessitate a thorough approach to capture biodiversity, its drivers and change thereof. To achieve the most informative vegetation assessment and monitoring, a systematic, nested sampling design comprising all types of stands is the most promising approach.

In order to obtain valid and more substantial scientific results that also meet the objectives of permanent monitoring, access to the interior of the forests for research purposes must be made possible. Obtaining scientific knowledge is only one building block on the path to environmental protection; another is found in the far-reaching impacts of social and economic contexts. Here, too, the preconditions for a sustainable implementation of conservation measures must be met. Future projects should build on the insights obtained in the current survey and use them as a starting point for targeted research into the parameters identified and their impacts on the vegetation in order to establish conclusive causal relationships.

Abstract

The stands surveyed are among the last closed canopy forests in Rwanda. Their exploration began in the early twentieth century and is still ongoing. Previous studies were mainly concerned with plant sociological issues and presented references to environmental factors in anecdotal form, at best using indirect ordination methods. The present study undertakes a classification of the vegetation with numerical methods and establishes quantitative relationships of the species' distributional structure to environmental parameters using spatially explicit procedures. For this purpose, 94 samples were taken in 100 m^2 hexagonal plots. Of these, 70 samples are from Nyungwe, 14 are from Gishwati, and 10 are from Cyamudongo.

Given the homogeneity of the terrain and vegetation, all vegetation types encountered, all types of stands, and all vegetation strata were included. The beta diversity is expressed by an average Bray-Curtis dissimilarity of 0.92, and in JOST'S (2007) numbers equivalents, 37.90 equally likely samples would be needed to represent the diversity encountered. Within the survey, 1198 species in 127 families were collected. Among the specimens are 6 local endemics and 40 Albertine Rift endemics.

Resulting from UPGMA and FCM-NC, 20 to 40 plant communities were established depending on the level of resolution. It can be inferred by means of a Mantel correlogram that the mean zone of influence of a single vegetation stand, as sampled by a 100 m^2 plot in Nyungwe Forest, ranges between 0.016 and 3.42 km. Of the communities compiled using FCM-NC and UPGMA, 50% consist of individual samples. Beyond undersampling, natural small-scale discontinuities are reflected by this result. Partial db-RDA resulted in an explained variation of 9.60% and 14.41% for environmental and soil factors, respectively. Utilising variation partitioning analyses based on CCA and tb-RDA, between 21.70% and 37.80% of the variation in vegetation data could be explained.

The spatially structured fraction of these parameters accounts for between 30.50% and 49.80% of the explained variation (100%). The purely environmental parameters account for a share of 10.30% to 16.30%, whereby the lower limit originates from the unimodal approach and has lost its statistical significance. The soil variables, also after partial analysis, account for a share of 19.00% to 35.70%. While the residual impact of the climatic parameters is hardly significant, the effect of the soil properties is prevalent. In general, the spatially structured fraction of the parameters is predominant here. While on the broad-scale climatic factors, the altitude a.s.l. and the geology are determining factors, some soil parameters and matrix components also show their impacts here. In the mid-range of the scale, it is the forest matrix, the soil types, and the geology that determine species distribution. While in the fine range of the scale, some unrecorded parameters seem to have an effect, there are also neutral processes that determine species composition.

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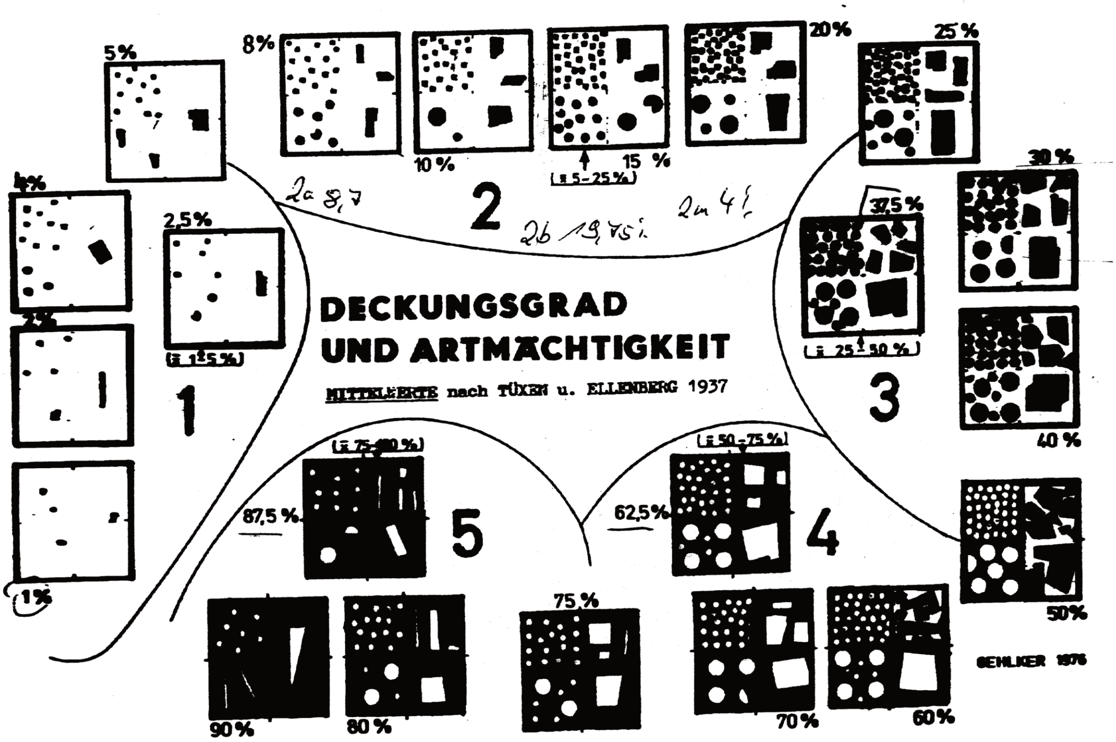
Annex



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Annex 1: Estimation aid. Gehlker, 1976.

Annex 2: Table of the FCM-NC membership probabilities. The annex is inserted as a folded table at the end.

Annex 3: Table of the pairwise Bray-Curtis dissimilarity values. The upper triangle of the matrix comprises the dissimilarities based on a data set containing only the species that occured at least twice in the survey. The lower triangle represents the dissimilarities based on a data set containing all the species that occured in the survey. The annex is inserted as a folded table at the end.

Annex 4: Table of the pairwise Raup-Crick probabilities of non-identical species composition. The null model "r1" (the probability of selecting species is proportional to the species frequencies) was used for the calculation. The annex is inserted as a folded table at the end.

Annex 5: Correlations between the independent variables are given in the lower half (r), the upper half contains the two-tailed probabilities that the columns are uncorrelated, p(uncorr). The folded table is inserted at the end. For the calculations, Past 3.15 (Hammer, 2017) was used.

Annex 31: Vegetation table. The annex is inserted as a folded table at the end.

Annex 32: Table with the values of the independent variables. The folded table is inserted at the end.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	Incli[ø]	24.1702	11.2672	4.2547
2	DegExp	172.7973	111.8051	1.4927
3	PreciMm	1719.6148	309.6912	4.4373
4	ElevS_IM	2322.9346	295.3062	26.0251
5	TB_60øC	14.7263	1.8246	17.4422
6	NEAR_DIS	785.3371	909.2236	34.7343
7	Solar_WH	2166280.376	127211.0378	4.2061
8	throuRoa	0.0619	0.241	5.1584
9	TreePlnt	0.127	0.333	7.0784
10	abv300	0.2705	0.4442	8.048
11	other	0.0434	0.2039	4.8862
12	trghRoEa	0.0418	0.2	3.1737
13	earRoaTr	0.0827	0.2755	5.3376
14	naroTrTe	0.0535	0.2251	5.9735
15	eRmosTT	0.0624	0.242	4.8989
16	mosTT	0.0473	0.2122	5.5425
17	Tea	0.0245	0.1545	3.9896
18	eaRoTrVi	0.0247	0.1553	2.5186
19	eaRotrTT	0.0159	0.1251	2.3516
20	erRoTPmo	0.0342	0.1816	2.7504
21	natintEg	0.025	0.1562	2.0376
22	mosTrPas	0.0203	0.1412	2.0578
23	Uwinka	0.0648	0.2461	0
24	W	0.1375	0.3444	20.9951
25	N	0.2201	0.4143	4.393
26	C	0.6424	0.4793	0
27	KS	0.0247	0.1552	2.0884
28	HM	0.4498	0.4975	3.4196
29	TS	0.0092	0.0954	1.5395
30	HU	0.0859	0.2803	3.0008
31	KH	0.1226	0.3279	3.5244
32	MH	0.0188	0.1357	1.668
33	KR	0.0121	0.1092	1.4759
34	KM	0.0128	0.1124	3.7115
35	HO	0.2642	0.4409	0
36	Hill_cur	0.2635	0.5105	1.7395
37	Hill_cur	0.4357	0.7042	1.6857
38	Terrain	2.8028	1.1879	4.1263
39	Surface	1.0627	0.2425	2.1644

Annex 6 A: see page 254. Variance Inflation Factors for first CCA approach using the environmental factors as explanatory variables.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	Na	3.8638	26.3649	1.717
2	K	27.0662	12.7755	3.1363
3	Ca	208.6347	326.1405	6.0047
4	Mg	15.5362	27.413	9.1908
5	PO	6.1419	6.3791	3.7124
6	N	4.5779	1.949	128.6779
7	H	0.001	0.0008	16.9485
8	CEC	7.019	2.985	5.1651
9	Ca_Al	43.903	296.0876	33.235
10	Mg_Al	2.5738	13.353	34.4317
11	HAHFC	0.444	0.4969	4.4028
12	HAHF	0.0635	0.2438	3.2628
13	DRDL	0.1331	0.3396	2.8647
14	HFFHA	0.0223	0.1477	2.1106
15	HCL	0.0216	0.1453	2.3474
16	TFH	0.007	0.0833	1.3093
17	VLVC	0.0426	0.202	2.34
18	HDC	0.266	0.4419	0
19	Lt_s	0.0065	0.0806	3.3873
20	Ut	0.009	0.0945	28.5358
21	T_l	0.0234	0.1513	63.1778
22	Sl	0.583	0.4931	10269.7415
23	Lu	0.0054	0.0734	1.4027
24	Su	0.0491	0.2162	1541.3615
25	Ls_2_3	0.0267	0.1611	30.1749
26	Us	0.0484	0.2146	144.3402
27	Lts	0.0185	0.1349	7.0591
28	Ls4	0.0108	0.1035	63.8495
29	St	0.0163	0.1268	1434.8186
30	US	0.0138	0.1165	45.2086
31	Ts	0.1889	0.3914	0
32	Soil_Dep	1.9098	9.4802	1.9346
33	S	0.1331	0.3396	0
34	V	0.007	0.0833	0
35	M	0.0426	0.202	0
36	W	0.8174	0.3864	0
37	Kf	42.2045	18.3819	11239.4353
38	clay	0.0938	0.2915	1.8268
39	stone	0.1604	0.367	2.331
40	diff	0.0578	0.2333	2.4231
41	loam	0.6881	0.4633	0
42	C	65.1348	33.1088	204.1916
43	Al	163.5168	115.6323	0
44	C_N	13.7744	2.5698	21.5809
45	PH	3.2618	0.5713	18.3301
46	æS	136.2586	80.028	10.7594
47	Stonecon	1.7802	6.3071	1.9279
48	GraniteS	0.3671	0.482	6.2843
49	Quarziti	0.2202	0.4144	6.7865
50	Sandston	0.0326	0.1777	1.9768
51	SlateMyl	0.1398	0.3467	8.4776
52	GraniteP	0.0654	0.2473	3.0813
53	Volcanic	0.0211	0.1436	2.5097
54	SlatePhy	0.1537	0.3607	0
55	TWI	13.904	0.7014	2.104

Annex 6 B: see page 254. Variance Inflation Factors for first CCA approach using the soil factors as explanatory variables.

Annex 7 A: see page 260. Variance Inflation Factors from a CCA approach using the environmental factors as explanatory variables. The result included some explanatory variables exceeding the 0.05 alpha-level for the adjusted R^2 values. Samples 47_{C} and 60_{C} had to be weighted-down.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	Incli[ø]	24.1312	11.3385	1.3073
3	PreciMm	1720.7184	311.6597	1.5989
4	ElevS_IM	2328.8602	292.9123	3.8506
6	NEAR_DIS	795.3317	911.3705	6.389
8	throuRoa	0.0628	0.2426	2.6833
9	TreePlnt	0.1288	0.3349	1.2898
12	trghRoEa	0.0423	0.2013	1.1663
15	eRmosTT	0.0633	0.2435	1.2187
19	eaRotrTT	0.0024	0.0491	1.013
23	Uwinka	0.0656	0.2476	1.398
24	W	0.1394	0.3463	6.9495
25	N	0.2231	0.4163	1.6713
26	C	0.6375	0.4807	0

Annex 7 B: see page 266. Variance Inflation Factors from a CCA approach using the soil factors as explanatory variables. The result included some explanatory variables exceeding the 0.05 alpha-level for the adjusted R^2 values. Samples 10_{NU}, 47_{C} and 60_{C} had to be weighted-down.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
4	Mg	14.7864	26.892	1.679
5	PO	5.8085	5.6322	1.2116
11	HAHFC	0.4392	0.4963	1.9174
12	HAHF	0.0645	0.2456	1.4404
17	VLVC	0.0433	0.2035	1.5537
39	stone	0.163	0.3694	1.1383
44	C_N	13.8596	2.502	3.2869
45	PH	3.2337	0.5224	3.3793
48	GraniteS	0.3732	0.4836	2.9589
49	Quarziti	0.2238	0.4168	2.4471
51	SlateMyl	0.13	0.3363	2.3279
54	SlatePhy	0.152	0.359	2.1422

Annex 8 A: see page 263. Variance Inflation Factors from a CCA approach using the environmental factors as explanatory variables. The result included some explanatory variables exceeding the 0.05 alpha-level for the adjusted R^2 values. Samples 47_{C} and 60_{C} had to be omitted.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
3	PreciMm	1720.9163	312.0109	1.551
4	ElevS_IM	2329.9228	292.4683	3.4831
6	NEAR_DIS	797.124	911.7433	6.1135
8	throuRoa	0.0629	0.2428	2.5223
9	TreePlnt	0.1291	0.3353	1.2392
22	Uwinka	0.0658	0.2479	1.3459
23	W	0.1397	0.3467	6.5252
24	N	0.2237	0.4167	1.5849
25	C	0.6366	0.481	0

Annex 8 B: See page 267. Variance Inflation Factors from a CCA approach using the soil factors as explanatory variables. All of the included explanatory variables are significant at least at the 0.05 alpha-level for the adjusted R^2 values. Samples 10_{NU} and 57_{C} had to be weighted-down and sample 60_{C} had to be omitted.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
3	Mg	14.7408	26.8516	1.7011
8	Ca_Al	15.809	64.3247	1.5124
10	HAHFC	0.4391	0.4963	1.5254
11	HAHF	0.0646	0.2457	1.3872
38	stone	0.1632	0.3695	1.1227
43	C_N	13.8642	2.4983	3.1515
44	PH	3.2323	0.5201	3.3887
47	GraniteS	0.3735	0.4837	1.9405
48	Quarziti	0.224	0.4169	1.5366
50	SlateMyl	0.1296	0.3358	1.8789

Name	Explains %	pseudo-F	P	P(adj)
Soil_text.Lu	3.6	3.4	0.001	0.00333
Ca_Al	3.3	3.1	0.015	0.02885
Mg_Al	3.3	3.1	0.002	0.00526
C_N	3.1	2.9	0.001	0.00333
Cat_Geol.SlateMylo	2.9	2.7	0.001	0.00333
pH	2.9	2.7	0.001	0.00333
H	2.3	2.2	0.001	0.00333
Cat_Geol.Quarzitic	2.3	2.2	0.001	0.00333
Soiltype_FAO.HAHF	2.3	2.2	0.001	0.00333
Mg	2.3	2.1	0.001	0.00333
PO	2.2	2.1	0.002	0.00526
Ca	2.1	1.9	0.001	0.00333
C	2	1.9	0.001	0.00333
Drainage.M	2	1.8	0.016	0.02963
Soiltype_FAO.VLVC	2	1.8	0.015	0.02885
Al	1.9	1.8	0.001	0.00333
CEC	1.9	1.8	0.001	0.00333
N	1.8	1.7	0.001	0.00333
Soil_text.Ls_2_3	1.8	1.7	0.068	0.11333
μS	1.8	1.7	0.002	0.00526
Cat_Geol.GraniteSedi	1.8	1.7	0.001	0.00333
Cat_Geol.SlatePhyllo	1.7	1.6	0.004	0.00909
Soiltype_FAO.DRDL	1.7	1.6	0.014	0.02885
Drainage.S	1.7	1.6	0.007	0.01522
Limitation.stone	1.7	1.5	0.004	0.00909
Drainage.W	1.6	1.5	0.004	0.00909
Cat_Geol.Sandstone	1.6	1.5	0.112	0.18065
Soiltype_FAO.HAHFC	1.5	1.4	0.002	0.00526
Drainage.V	1.5	1.4	0.216	0.28421
Soiltype_FAO.TFH	1.5	1.4	0.197	0.26622
Limitation.loam	1.5	1.4	0.001	0.00333
Cat_Geol.Volcanic	1.5	1.4	0.19	0.26389
Soiltype_FAO.HFFHA	1.5	1.4	0.174	0.25429
Soil_text.Su	1.4	1.4	0.135	0.20455
Cat_Geol.GranitePara	1.4	1.3	0.125	0.19531
K	1.3	1.2	0.059	0.10172
Soiltype_FAO.HDC	1.3	1.2	0.045	0.08036
Soiltype_FAO.HCL	1.3	1.2	0.266	0.34103
Soil_text.Ts	1.2	1.2	0.178	0.25429
Limitation.clay	1.2	1.1	0.305	0.37195
TWI	1.2	1.1	0.286	0.3575
Soil_text.T_l	1.2	1.1	0.35	0.41667
kf	1.1	1	0.451	0.52442
Stonecontent	1	1	0.472	0.52444
Soil_text.Ls4	1	0.9	0.47	0.52444
Soil_text.Us	0.9	0.9	0.588	0.6
Soil_text.Sl	0.9	0.9	0.917	0.917
Soil_text.St	0.9	0.8	0.547	0.56979
Limitation.diff	0.8	0.8	0.724	0.724
Soil_text.US	0.8	0.8	0.496	0.53913
Soil_Depth_m	0.8	0.8	0.539	0.56979
Na	0.7	0.6	0.658	0.658
Soil_text.Lts	0.6	0.6	0.707	0.707
Soil_text.Lt_s	0.6	0.5	0.706	0.706
Soil_text.Ut	0.5	0.5	0.759	0.759

Annex 9 A: P(adj) obtained by the correction for false discovery rate; The simple effects of the soil parameters ordered by percentage explained. The percentage explained and P-values were obtained per Monte-Carlo permutation.

Name	Explains %	pseudo-F	P	P(adj)
Soil_text.Lu	3.61	3.4	0.001	0.00714
Ca_Al	3.3	3.2	0.001	0.00714
C_N	2.93	2.9	0.001	0.00714
Cat_Geol.SlateMylo	2.5	2.5	0.001	0.00714
pH	2.16	2.2	0.001	0.00714
Cat_Geol.Quarzitic	2.05	2.1	0.001	0.00714
Mg_Al	1.97	2.1	0.046	0.14375
H	1.77	1.9	0.002	0.0125
Cat_Geol.GraniteSedi	1.56	1.7	0.001	0.00714
Cat_Geol.Sandstone	1.56	1.7	0.034	0.12143
PO	1.54	1.7	0.005	0.02778
Drainage.V	1.48	1.6	0.171	0.32407
Drainage.M	1.48	1.6	0.028	0.10769
Soiltype_FAO.HAHF	1.49	1.7	0.006	0.03
Cat_Geol.GranitePara	1.44	1.6	0.013	0.05417
Soil_text.Ls_2_3	1.4	1.6	0.053	0.15588
Soiltype_FAO.HFFHA	1.33	1.5	0.087	0.20714
Soiltype_FAO.HCL	1.4	1.6	0.042	0.14
Cat_Geol.Volcanic	1.27	1.5	0.103	0.22391
Cat_Geol.SlatePhyllo	1.27	1.5	unknown	unknown
Soil_Depth_m	1.36	1.6	0.096	0.21818
Limitation.stone	1.27	1.5	0.01	0.04545
Mg	1.13	1.3	0.066	0.18333
Drainage.S	1.06	1.3	0.083	0.20714
Soiltype_FAO.DRDL	1.06	1.3	unknown	unknown
Drainage.W	1.06	1.3	unknown	unknown
Soil_text.Ls4	1.04	1.2	0.259	0.44655
Limitation.clay	1.02	1.2	0.153	0.306
Soil_text.Ts	1.06	1.3	0.084	0.20714
Soiltype_FAO.HAHFC	0.99	1.2	0.118	0.24583
Soiltype_FAO.HDC	0.99	1.2	unknown	unknown
Soil_text.Su	0.99	1.2	0.205	0.36607
Al	0.96	1.2	0.175	0.32407
CEC	0.9	1.1	0.297	0.495
Soil_text.T_l	0.85	1	0.41	0.66129
Soil_text.US	0.78	0.9	0.484	0.75625
N	0.8	1	0.537	0.76714
Soil_text.St	0.78	0.9	0.511	0.76714
C	0.75	0.9	0.625	0.84459
K	0.75	0.9	0.647	0.85132
Stonecontent	0.75	0.9	0.616	0.84459
TWI	0.73	0.9	0.705	0.86951
Soil_text.Us	0.7	0.8	0.713	0.86951
Limitation.diff	0.69	0.8	0.738	0.87857
Limitation.loam	0.69	0.8	unknown	unknown
Na	0.66	0.8	0.691	0.86951
μS	0.65	0.8	0.888	0.96522
Soil_text.Lt_s	0.56	0.7	0.801	0.91023
Soil_text.Ut	0.57	0.7	0.799	0.91023
Soil_text.Lts	0.55	0.6	0.871	0.96522
Soil_text.Sl	0.55	0.6	unknown	unknown
kf	0.79	0.9	0.523	0.76714

Annex 9 B: See page 206. P(adj) obtained by the correction for false discovery rate. The conditional effects of the soil parameters. The percentage explained and P-values were obtained per Monte-Carlo permutation, after the inclusion of the predictors placed above in the list. From the difference in the orders of the variables in the respective table, correlations between the variables can be inferred.

Annex 10 A: see page 270. Variance Inflation Factors from a CCA approach using the environmental factors as explanatory variables and the soil factors as covariates. Samples 47_C and 60_C had to be omitted.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
2	PreciMm	1720.032	312.6447	4.7719
3	ElevS_IM	2329.1263	293.0787	6.333
5	NEAR_DIS	788.4371	906.7216	4.4858
7	TreePlnt	0.1298	0.3361	2.377
20	Uwinka	0.0662	0.2486	1.8736

Annex 10 B: See page 271. Variance Inflation Factors from a CCA approach using the soil factors as explanatory variables and the environmental factors as covariates. Samples 10_{NU} and 57_C had to be weighted-down and sample 60_C had to be omitted.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	Ca_Al	14.0263	57.0493	2.1947
2	Mg_Al	1.2925	6.009	2.2941
4	HAHF	0.0648	0.2462	2.1045
16	C_N	13.8873	2.4792	6.1664
17	PH	3.2238	0.5028	7.9069
21	Sandston	0.0333	0.1795	6.2338
22	SlateMyl	0.1266	0.3325	7.1218
23	GraniteP	0.0669	0.2498	2.5945

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PreciMm	1720.032	312.6447	12.0357
2	ElevS_IM	2329.1263	293.0787	9.9582
3	NEAR_DIS	788.4371	906.7216	34.9084
4	throuRoa	0.0578	0.2333	4.7255
5	TreePlnt	0.1298	0.3361	16.8792
6	abv300	0.2764	0.4472	23.4615
7	other	0.0444	0.206	8.3273
8	trghRoEa	0.0427	0.2021	10.3329
9	earRoaTr	0.0845	0.2782	13.6425
10	naroTrTe	0.0547	0.2274	9.0776
11	eRmosTT	0.0638	0.2444	10.9754
12	mosTT	0.0483	0.2144	8.266
13	Tea	0.025	0.1561	5.3579
14	eaRoTrVi	0.0253	0.157	4.8421
15	erRoTPmo	0.0349	0.1835	8.8107
16	natintEg	0.0256	0.1578	5.2199
17	mosTrPas	0.0208	0.1427	4.5345
18	Uwinka	0.0662	0.2486	0
19	W	0.1405	0.3475	24.1284
20	N	0.2249	0.4175	9.1483
21	C	0.6346	0.4815	0

Annex 11 A: See page 273. Variance Inflation Factors from a Variation Partitioning approach based on a CCA using two groups of explanatory variables. The first group comprises the environmental factors, the second group comprises the soil factors. The conditional effects of the groups have been tested. The VIFs within group one are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	Ca_Al	14.0263	57.0493	2.3491
2	Mg_Al	1.2925	6.009	3.2563
3	HAHFC	0.4374	0.4961	4.3464
4	HAHF	0.0648	0.2462	2.405
5	DRDL	0.1359	0.3427	2.7174
6	HFFHA	0.0228	0.1493	4.1845
7	HCL	0.0221	0.1469	2.8491
8	TFH	0.0071	0.0842	1.291
9	VLVC	0.0435	0.204	7.204
10	HDC	0.2663	0.442	0
11	C_N	13.8873	2.4792	6.8043
12	PH	3.2238	0.5028	9.5528
13	GraniteS	0.3751	0.4842	26.7097
14	Quarziti	0.225	0.4176	12.3525
15	Sandston	0.0333	0.1795	10.0339
16	SlateMyl	0.1266	0.3325	12.6613
17	GraniteP	0.0669	0.2498	12.5225
18	Volcanic	0.0215	0.1452	4.7415
19	SlatePhy	0.1516	0.3586	0

Annex 11 B: See page 273. Variance Inflation Factors from a Variation Partitioning approach based on a CCA using two groups of explanatory variables. The first group comprises the environmental factors, the second group comprises the soil factors. The conditional effects of the groups have been tested. The VIFs within group two are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PreciMm	1720.032	312.6447	12.0357
2	ElevS_IM	2329.1263	293.0787	9.9582
3	NEAR_DIS	788.4371	906.7216	34.9084
4	throuRoa	0.0578	0.2333	4.7255
5	TreePlnt	0.1298	0.3361	16.8792
6	abv300	0.2764	0.4472	23.4615
7	other	0.0444	0.206	8.3273
8	trghRoEa	0.0427	0.2021	10.3329
9	earRoaTr	0.0845	0.2782	13.6425
10	naroTrTe	0.0547	0.2274	9.0776
11	eRmosTT	0.0638	0.2444	10.9754
12	mosTT	0.0483	0.2144	8.266
13	Tea	0.025	0.1561	5.3579
14	eaRoTrVi	0.0253	0.157	4.8421
15	erRoTPmo	0.0349	0.1835	8.8107
16	natintEg	0.0256	0.1578	5.2199
17	mosTrPas	0.0208	0.1427	4.5345
18	Uwinka	0.0662	0.2486	0
19	W	0.1405	0.3475	24.1284
20	N	0.2249	0.4175	9.1483
21	C	0.6346	0.4815	0
22	Ca_Al	14.0263	57.0493	2.3491
23	Mg_Al	1.2925	6.009	3.2563
24	HAHFC	0.4374	0.4961	4.3464
25	HAHF	0.0648	0.2462	2.405
26	DRDL	0.1359	0.3427	2.7174
27	HFFHA	0.0228	0.1493	4.1845
28	HCL	0.0221	0.1469	2.8491
29	TFH	0.0071	0.0842	1.291
30	VLVC	0.0435	0.204	7.204
31	HDC	0.2663	0.442	0
32	C_N	13.8873	2.4792	6.8043
33	PH	3.2238	0.5028	9.5528
34	GraniteS	0.3751	0.4842	26.7097
35	Quarziti	0.225	0.4176	12.3525
36	Sandston	0.0333	0.1795	10.0339
37	SlateMyl	0.1266	0.3325	12.6613
38	GraniteP	0.0669	0.2498	12.5225
39	Volcanic	0.0215	0.1452	4.7415
40	SlatePhy	0.1516	0.3586	0

Annex 11 C: See page 273. Variance Inflation Factors from a Variation Partitioning approach based on a CCA using two groups of explanatory variables. The first group comprises the environmental factors, the second group comprises the soil factors. The conditional effects of the groups have been tested. The VIFs within the explanatory variables are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
3	PreciMm	1719.1413	311.8526	1.619
4	ElevS_IM	2316.8085	296.8281	3.2227
6	NEAR_DIS	772.7827	889.0127	6.2508
8	throuRoa	0.0745	0.2625	2.6068
9	TreePlnt	0.1277	0.3337	1.283
12	trghRoEa	0.0426	0.2018	1.1387
13	earRoaTr	0.0851	0.279	1.2246
23	Uwinka	0.0638	0.2444	1.3091
24	W	0.117	0.3214	5.1606
25	N	0.2128	0.4093	1.6713
26	C	0.6702	0.4701	0

Annex 12 A: See page 275. Variance Inflation Factors from a db-RDA. In the first approach the environmental factors were used as explanatory variables. The VIFs given in the table remain after interactive forward selection of the independent variables.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
9	Mg_Al	2.9103	14.7133	1.7558
11	HAHF	0.0745	0.2625	1.5016
12	DRDL	0.117	0.3214	1.7264
16	VLVC	0.0426	0.2018	1.2146
22	Lu	0.0106	0.1026	1.2039
38	stone	0.1596	0.3662	1.2242
42	Al	158.1886	112.7846	1.5947
43	C_N	13.5966	2.6133	3.3999
44	PH	3.3005	0.5869	3.6002
47	GraniteS	0.3617	0.4805	2.994
48	Quarziti	0.2128	0.4093	3.0174
49	Sandston	0.0319	0.1758	1.3382
50	SlateMyl	0.1489	0.356	2.7001
51	GraniteP	0.0638	0.2444	1.7697
52	Volcanic	0.0213	0.1443	1.2614
53	SlatePhy	0.1596	0.3662	0

Annex 12 B: See page 275. Variance Inflation Factors from a db-RDA. In the second approach the soilfactors were used as explanatory variables. The VIFs given in the table remain after interactive forward selection of the independent variables.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PreciMm	1719.1413	311.8526	8.0287
2	ElevS_IM	2316.8085	296.8281	8.1419
3	NEAR_DIS	772.7827	889.0127	7.3969
18	mosTrPas	0.0213	0.1443	2.5559
19	Uwinka	0.0638	0.2444	2.2676
21	N	0.2128	0.4093	4.9677

Annex 13 A: See page 276. Variance Inflation Factors from a partial db-RDA. In this approach the environmental factors s.l. were used as explanatory variables and the soil factors as covariables. The VIFs given in the table remain after interactive forward selection of the independent variables.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
9	Mg_Al	2.9103	14.7133	1.7558
11	HAHF	0.0745	0.2625	1.5016
12	DRDL	0.117	0.3214	1.7264
16	VLVC	0.0426	0.2018	1.2146
22	Lu	0.0106	0.1026	1.2039
38	stone	0.1596	0.3662	1.2242
42	Al	158.1886	112.7846	1.5947
43	C_N	13.5966	2.6133	3.3999
44	PH	3.3005	0.5869	3.6002
47	GraniteS	0.3617	0.4805	2.994
48	Quarziti	0.2128	0.4093	3.0174
49	Sandston	0.0319	0.1758	1.3382
50	SlateMyl	0.1489	0.356	2.7001
51	GraniteP	0.0638	0.2444	1.7697
52	Volcanic	0.0213	0.1443	1.2614
53	SlatePhy	0.1596	0.3662	0

Annex 13 B: See page 276. Variance Inflation Factors from a partial db-RDA. In the this approach the soil factors were used as explanatory variables and the environmental factors s.l. as covariables. The VIFs given in the table remain after interactive forward selection of the independent variables.

Annex 14 A: See page 286. Variance Inflation Factors from a tb-RDA. In the first approach the environmental factors were used as explanatory variables. The VIFs given in the table remain after interactive forward selection of the independent variables.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
3	PreciMm	1719.1413	311.8526	1.6989
4	ElevS_IM	2316.8085	296.8281	3.2704
6	NEAR_DIS	772.7827	889.0127	6.5452
8	throuRoa	0.0745	0.2625	2.6345
9	TreePlnt	0.1277	0.3337	1.3015
12	trghRoEa	0.0426	0.2018	1.1452
13	earRoaTr	0.0851	0.279	1.2559
15	eRmosTT	0.0532	0.2244	1.2103
23	Uwinka	0.0638	0.2444	1.3111
24	W	0.117	0.3214	5.2944
25	N	0.2128	0.4093	1.6744
26	C	0.6702	0.4701	0

Annex 14 B: See page 286. Variance Inflation Factors from a tb-RDA. In the second approach the soilfactors were used as explanatory variables. The VIFs given in the table remain after interactive forward selection of the independent variables.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
10	Mg_Al	2.9103	14.7133	1.7755
11	HAHFC	0.4574	0.4982	2.105
12	HAHF	0.0745	0.2625	1.4962
14	HFFHA	0.0213	0.1443	1.3093
15	HCL	0.0213	0.1443	1.3944
17	VLVC	0.0426	0.2018	1.5338
35	stone	0.1596	0.3662	1.3227
40	C_N	13.5966	2.6133	3.3515
41	PH	3.3005	0.5869	3.5762
44	GraniteS	0.3617	0.4805	3.0332
45	Quarziti	0.2128	0.4093	2.0428
46	Sandston	0.0319	0.1758	1.3063
47	SlateMyl	0.1489	0.356	3.1039
48	GraniteP	0.0638	0.2444	1.4758
49	Volcanic	0.0213	0.1443	1.2591
50	SlatePhy	0.1596	0.3662	0

Annex 15 A: See page 290. Variance Inflation Factors from a partial tb-RDA. In this approach the environmental factors s.l. were used as explanatory variables and the soil factors as covariables. The VIFs given in the table remain after interactive forward selection of the independent variables.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
3	PreciMm	1719.1413	311.8526	5.0238
4	ElevS_IM	2316.8085	296.8281	5.6677
9	TreePlnt	0.1277	0.3337	1.7167
21	natintEg	0.0213	0.1443	1.3469
23	Uwinka	0.0638	0.2444	1.7071
26	C	0.6702	0.4701	3.3696

Annex 15 B: See page 290. Variance Inflation Factors from a partial tb-RDA. In the this approach the soil factors were used as explanatory variables and the environmental factors s.l. as covariables. The VIFs given in the table remain after interactive forward selection of the independent variables.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
10	Mg_Al	2.9103	14.7133	3.1167
11	HAHFC	0.4574	0.4982	2.7617
12	HAHF	0.0745	0.2625	2.4038
35	stone	0.1596	0.3662	2.535
39	Al	158.1886	112.7846	2.7306
40	C_N	13.5966	2.6133	5.7495
41	PH	3.3005	0.5869	11.6558
44	GraniteS	0.3617	0.4805	6.7144
45	Quarziti	0.2128	0.4093	7.7144
46	Sandston	0.0319	0.1758	6.1256
47	SlateMyl	0.1489	0.356	8.4963
49	Volcanic	0.0213	0.1443	4.1963

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PreciMm	1719.1413	311.8526	13.5643
2	ElevS_IM	2316.8085	296.8281	9.2943
3	NEAR_DIS	772.7827	889.0127	36.6323
4	throuRoa	0.0745	0.2625	6.2948
5	TreePlnt	0.1277	0.3337	18.8756
6	abv300	0.2766	0.4473	23.7617
7	other	0.0426	0.2018	8.4944
8	trghRoEa	0.0426	0.2018	10.1427
9	earRoaTr	0.0851	0.279	14.609
10	naroTrTe	0.0532	0.2244	9.97
11	eRmosTT	0.0532	0.2244	10.2612
12	mosTT	0.0426	0.2018	7.564
13	Tea	0.0213	0.1443	4.7277
14	eaRoTrVi	0.0213	0.1443	5.421
15	eaRotrTT	0.0213	0.1443	9.1434
16	erRoTPmo	0.0319	0.1758	8.7595
17	natintEg	0.0213	0.1443	4.3923
18	mosTrPas	0.0213	0.1443	4.6657
19	Uwinka	0.0638	0.2444	0
20	W	0.117	0.3214	18.9344
21	N	0.2128	0.4093	7.8415
22	C	0.6702	0.4701	0

Annex 16 A: See page 294. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using two groups of explanatory variables. The first group comprises the environmental factors, the second group comprises the soil factors. The conditional effects of the groups have been tested. The VIFs within group one are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	Mg_Al	2.9103	14.7133	3.2593
2	HAHFC	0.4574	0.4982	4.0218
3	HAHF	0.0745	0.2625	2.8673
4	DRDL	0.117	0.3214	2.7476
5	HFFHA	0.0213	0.1443	3.5868
6	HCL	0.0213	0.1443	2.8834
7	TFH	0.0106	0.1026	1.4529
8	VLVC	0.0426	0.2018	6.8218
9	HDC	0.2553	0.436	0
10	clay	0.0957	0.2942	1.8746
11	stone	0.1596	0.3662	2.76
12	diff	0.0532	0.2244	1.326
13	loam	0.6915	0.4619	0
14	C_N	13.5966	2.6133	6.8635
15	PH	3.3005	0.5869	10.7838
16	GraniteS	0.3617	0.4805	29.4849
17	Quarziti	0.2128	0.4093	14.5112
18	Sandston	0.0319	0.1758	9.6638
19	SlateMyl	0.1489	0.356	16.0314
20	GraniteP	0.0638	0.2444	13.0735
21	Volcanic	0.0213	0.1443	5.1805
22	SlatePhy	0.1596	0.3662	0

Annex 16 B: See page 294. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using two groups of explanatory variables. The first group comprises the environmental factors, the second group comprises the soil factors. The conditional effects of the groups have been tested. The VIFs within group two are shown.

Annex 16 C: See page 294. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using two groups of explanatory variables. The first group comprises the environmental factors, the second group comprises the soil factors. The conditional effects of the groups have been tested. The VIFs within the explanatory variables are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PreciMm	1719.1413	311.8526	13.5643
2	ElevS_IM	2316.8085	296.8281	9.2943
3	NEAR_DIS	772.7827	889.0127	36.6323
4	throuRoa	0.0745	0.2625	6.2948
5	TreePlnt	0.1277	0.3337	18.8756
6	abv300	0.2766	0.4473	23.7617
7	other	0.0426	0.2018	8.4944
8	trghRoEa	0.0426	0.2018	10.1427
9	earRoaTr	0.0851	0.279	14.609
10	naroTrTe	0.0532	0.2244	9.97
11	eRmosTT	0.0532	0.2244	10.2612
12	mosTT	0.0426	0.2018	7.564
13	Tea	0.0213	0.1443	4.7277
14	eaRoTrVi	0.0213	0.1443	5.421
15	eaRotrTT	0.0213	0.1443	9.1434
16	erRoTPmo	0.0319	0.1758	8.7595
17	natintEg	0.0213	0.1443	4.3923
18	mosTrPas	0.0213	0.1443	4.6657
19	Uwinka	0.0638	0.2444	0
20	W	0.117	0.3214	18.9344
21	N	0.2128	0.4093	7.8415
22	C	0.6702	0.4701	0
23	Mg_Al	2.9103	14.7133	3.2593
24	HAHFC	0.4574	0.4982	4.0218
25	HAHF	0.0745	0.2625	2.8673
26	DRDL	0.117	0.3214	2.7476
27	HFFHA	0.0213	0.1443	3.5868
28	HCL	0.0213	0.1443	2.8834
29	TFH	0.0106	0.1026	1.4529
30	VLVC	0.0426	0.2018	6.8218
31	HDC	0.2553	0.436	0
32	clay	0.0957	0.2942	1.8746
33	stone	0.1596	0.3662	2.76
34	diff	0.0532	0.2244	1.326
35	loam	0.6915	0.4619	0
36	C_N	13.5966	2.6133	6.8635
37	PH	3.3005	0.5869	10.7838
38	GraniteS	0.3617	0.4805	29.4849
39	Quarziti	0.2128	0.4093	14.5112
40	Sandston	0.0319	0.1758	9.6638
41	SlateMyl	0.1489	0.356	16.0314
42	GraniteP	0.0638	0.2444	13.0735
43	Volcanic	0.0213	0.1443	5.1805
44	SlatePhy	0.1596	0.3662	0

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PreciMm	1720.032	312.6447	17.7894
2	ElevS_IM	2329.1263	293.0787	24.2602
3	NEAR_DIS	788.4371	906.7216	44.1194
4	throuRoa	0.0578	0.2333	5.472
5	TreePlnt	0.1298	0.3361	1143.4529
6	abv300	0.2764	0.4472	1976.0661
7	other	0.0444	0.206	403.3242
8	trghRoEa	0.0427	0.2021	348.1218
9	earRoaTr	0.0845	0.2782	740.7145
10	naroTrTe	0.0547	0.2274	512.5019
11	eRmosTT	0.0638	0.2444	580.164
12	mosTT	0.0483	0.2144	466.7967
13	Tea	0.025	0.1561	258.176
14	eaRoTrVi	0.0253	0.157	218.2358
15	erRoTPmo	0.0349	0.1835	333.5052
16	natintEg	0.0256	0.1578	256.7418
17	mosTrPas	0.0208	0.1427	198.3641
18	Uwinka	0.0662	0.2486	0
19	W	0.1405	0.3475	71.4321
20	N	0.2249	0.4175	30.0486
21	C	0.6346	0.4815	0
22	Ca_Al	14.0263	57.0493	2.7293
23	Mg_Al	1.2925	6.009	3.8146
24	HAHFC	0.4374	0.4961	4.7303
25	HAHF	0.0648	0.2462	3.9397
26	DRDL	0.1359	0.3427	3.9497
27	HFFHA	0.0228	0.1493	19.7138
28	HCL	0.0221	0.1469	17.5966
29	TFH	0.0071	0.0842	1.6046
30	VLVC	0.0435	0.204	9.2206
31	HDC	0.2663	0.442	0
32	C_N	13.8873	2.4792	8.4259
33	PH	3.2238	0.5028	11.4881
34	GraniteS	0.3751	0.4842	58.7501
35	Quarziti	0.225	0.4176	28.8995
36	Sandston	0.0333	0.1795	26.5211
37	SlateMyl	0.1266	0.3325	81.2675
38	GraniteP	0.0669	0.2498	32.1624
39	Volcanic	0.0215	0.1452	6.8772
40	SlatePhy	0.1516	0.3586	0

Annex 17 A: See page 309. Variance Inflation Factors from a Variation Partitioning approach based on a CCA using two groups of explanatory variables. The first group comprises the environmental factors s. l., the second group comprises the spatial predictors computed from the XY coordinates. The conditional effects of the groups have been tested. The VIFs within group one are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PCO.1	-0.0388	1.39	1.0012
2	PCO.2	0.02	1.2962	1.0024
3	PCO.3	0.0537	1.1568	1.0076
4	PCO.4	-0.0109	0.9176	1.0014
5	PCO.5	-0.0433	0.9322	1.0053
6	PCO.10	0.0072	0.7725	1

Annex 17 B: See page 309. Variance Inflation Factors from a Variation Partitioning approach based on a CCA using two groups of explanatory variables. The second group comprises the db-MEM computed from the XY coordinates. The conditional effects of the groups have been tested. The VIFs within group two are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PreciMm	1720.032	312.6447	17.7894
2	ElevS_IM	2329.1263	293.0787	24.2602
3	NEAR_DIS	788.4371	906.7216	44.1194
4	throuRoa	0.0578	0.2333	5.472
5	TreePlnt	0.1298	0.3361	1143.4529
6	abv300	0.2764	0.4472	1976.0661
7	other	0.0444	0.206	403.3242
8	trghRoEa	0.0427	0.2021	348.1218
9	earRoaTr	0.0845	0.2782	740.7145
10	naroTrTe	0.0547	0.2274	512.5019
11	eRmosTT	0.0638	0.2444	580.164
12	mosTT	0.0483	0.2144	466.7967
13	Tea	0.025	0.1561	258.176
14	eaRoTrVi	0.0253	0.157	218.2358
15	erRoTPmo	0.0349	0.1835	333.5052
16	natintEg	0.0256	0.1578	256.7418
17	mosTrPas	0.0208	0.1427	198.3641
18	Uwinka	0.0662	0.2486	0
19	W	0.1405	0.3475	71.4321
20	N	0.2249	0.4175	30.0486
21	C	0.6346	0.4815	0
22	Ca_Al	14.0263	57.0493	2.7293
23	Mg_Al	1.2925	6.009	3.8146
24	HAHFC	0.4374	0.4961	4.7303
25	HAHF	0.0648	0.2462	3.9397
26	DRDL	0.1359	0.3427	3.9497
27	HFFHA	0.0228	0.1493	19.7138
28	HCL	0.0221	0.1469	17.5966
29	TFH	0.0071	0.0842	1.6046
30	VLVC	0.0435	0.204	9.2206
31	HDC	0.2663	0.442	0
32	C_N	13.8873	2.4792	8.4259
33	PH	3.2238	0.5028	11.4881
34	GraniteS	0.3751	0.4842	58.7501
35	Quarziti	0.225	0.4176	28.8995
36	Sandston	0.0333	0.1795	26.5211
37	SlateMyl	0.1266	0.3325	81.2675
38	GraniteP	0.0669	0.2498	32.1624
39	Volcanic	0.0215	0.1452	6.8772
40	SlatePhy	0.1516	0.3586	0
41	PCO.1	-0.0388	1.39	997.533
42	PCO.2	0.02	1.2962	51.2357
43	PCO.3	0.0537	1.1568	71.2067
44	PCO.4	-0.0109	0.9176	21.9728
45	PCO.5	-0.0433	0.9322	31.9966
46	PCO.10	0.0072	0.7725	52.5806

Annex 17 C: See page 309. Variance Inflation Factors from a Variation Partitioning approach based on a CCA using two groups of explanatory variables. The first group comprises the environmental factors s. l., the second group comprises the spatial predictors computed from the XY coordinates. The conditional effects of the groups have been tested. The VIFs within the explanatory variables are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PreciMm	1719.1413	311.8526	295.5382
2	ElevS_IM	2316.8085	296.8281	54.5018
3	NEAR_DIS	772.7827	889.0127	121.0786
4	throuRoa	0.0745	0.2625	16.6504
5	TreePlnt	0.1277	0.3337	1608.3075
6	abv300	0.2766	0.4473	2921.5448
7	other	0.0426	0.2018	683.1412
8	trghRoEa	0.0426	0.2018	651.5842
9	earRoaTr	0.0851	0.279	1104.731
10	naroTrTe	0.0532	0.2244	729.683
11	eRmosTT	0.0532	0.2244	765.5341
12	mosTT	0.0426	0.2018	600.9231
13	Tea	0.0213	0.1443	309.1108
14	eaRoTrVi	0.0213	0.1443	330.3073
15	eaRotrTT	0.0213	0.1443	288.847
16	erRoTPmo	0.0319	0.1758	446.1804
17	natintEg	0.0213	0.1443	297.57
18	mosTrPas	0.0213	0.1443	309.1358
19	Uwinka	0.0638	0.2444	0
20	W	0.117	0.3214	113.4214
21	N	0.2128	0.4093	180.2778
22	C	0.6702	0.4701	0
23	Mg_Al	2.9103	14.7133	3.6828
24	HAHFC	0.4574	0.4982	6.3041
25	HAHF	0.0745	0.2625	4.4839
26	DRDL	0.117	0.3214	4.5849
27	HFFHA	0.0213	0.1443	291.7538
28	HCL	0.0213	0.1443	288.4461
29	TFH	0.0106	0.1026	2.249
30	VLVC	0.0426	0.2018	11.5909
31	HDC	0.2553	0.436	0
32	clay	0.0957	0.2942	2.2363
33	stone	0.1596	0.3662	5.0702
34	diff	0.0532	0.2244	1.6592
35	loam	0.6915	0.4619	0
36	C_N	13.5966	2.6133	12.7109
37	PH	3.3005	0.5869	16.6335
38	GraniteS	0.3617	0.4805	131.9438
39	Quarziti	0.2128	0.4093	80.3851
40	Sandston	0.0319	0.1758	46.1316
41	SlateMyl	0.1489	0.356	335.3247
42	GraniteP	0.0638	0.2444	236.7709
43	Volcanic	0.0213	0.1443	19.5843
44	SlatePhy	0.1596	0.3662	0

Annex 18 A: See page 310. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using two groups of explanatory variables. The first group comprises the environmental factors s. l., the second group comprises the spatial predictors computed from the XY coordinates. The conditional effects of the groups have been tested. The VIFs within group one are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PreciMm	1719.1413	311.8526	295.5382
2	ElevS_IM	2316.8085	296.8281	54.5018
3	NEAR_DIS	772.7827	889.0127	121.0786
4	throuRoa	0.0745	0.2625	16.6504
5	TreePlnt	0.1277	0.3337	1608.3075
6	abv300	0.2766	0.4473	2921.5448
7	other	0.0426	0.2018	683.1412
8	trghRoEa	0.0426	0.2018	651.5842
9	earRoaTr	0.0851	0.279	1104.731
10	naroTrTe	0.0532	0.2244	729.683
11	eRmosTT	0.0532	0.2244	765.5341
12	mosTT	0.0426	0.2018	600.9231
13	Tea	0.0213	0.1443	309.1108
14	eaRoTrVi	0.0213	0.1443	330.3073
15	eaRotrTT	0.0213	0.1443	288.847
16	erRoTPmo	0.0319	0.1758	446.1804
17	natintEg	0.0213	0.1443	297.57
18	mosTrPas	0.0213	0.1443	309.1358
19	Uwinka	0.0638	0.2444	0
20	W	0.117	0.3214	113.4214
21	N	0.2128	0.4093	180.2778
22	C	0.6702	0.4701	0
23	Mg_Al	2.9103	14.7133	3.6828
24	HAHFC	0.4574	0.4982	6.3041
25	HAHF	0.0745	0.2625	4.4839
26	DRDL	0.117	0.3214	4.5849
27	HFFHA	0.0213	0.1443	291.7538
28	HCL	0.0213	0.1443	288.4461
29	TFH	0.0106	0.1026	2.249
30	VLVC	0.0426	0.2018	11.5909
31	HDC	0.2553	0.436	0
32	clay	0.0957	0.2942	2.2363
33	stone	0.1596	0.3662	5.0702
34	diff	0.0532	0.2244	1.6592
35	loam	0.6915	0.4619	0
36	C_N	13.5966	2.6133	12.7109
37	PH	3.3005	0.5869	16.6335
38	GraniteS	0.3617	0.4805	131.9438
39	Quarziti	0.2128	0.4093	80.3851
40	Sandston	0.0319	0.1758	46.1316
41	SlateMyl	0.1489	0.356	335.3247
42	GraniteP	0.0638	0.2444	236.7709
43	Volcanic	0.0213	0.1443	19.5843
44	SlatePhy	0.1596	0.3662	0
45	PCO.1	0	1.4382	1386.7115
46	PCO.2	0	1.2469	70.3998
47	PCO.3	0	1.1557	87.5714
48	PCO.4	0	1.047	99.3899
49	PCO.5	0	0.9397	61.4518
50	PCO.7	0	0.7805	31.2855
51	PCO.8	0	0.7576	30.5851
52	PCO.9	0	0.7556	50.1599
53	PCO.10	0	0.7514	380.2158
54	PCO.11	0	0.6545	115.4968

Annex 18 B: See page 310. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using two groups of explanatory variables. The first group comprises the environmental factors s. l., the second group comprises the spatial predictors computed from the XY coordinates. The conditional effects of the groups have been tested. The VIFs within the explanatory variables are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
55	PCO.12	0	0.6489	53.9637
56	PCO.13	0	0.6164	48.0015
57	PCO.15	0	0.5174	66.1117
58	PCO.16	0	0.438	59.8631
59	PCO.18	0	0.4378	26.8094
60	PCO.24	0	0.0549	2.2898

Annex 18 B: See page 310. Continued.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PCO.1	0	1.4382	1
2	PCO.2	0	1.2469	1
3	PCO.3	0	1.1557	1
4	PCO.4	0	1.047	1
5	PCO.5	0	0.9397	1
7	PCO.7	0	0.7805	1
8	PCO.8	0	0.7576	1
9	PCO.9	0	0.7556	1
10	PCO.10	0	0.7514	1
11	PCO.11	0	0.6545	1
12	PCO.12	0	0.6489	1
13	PCO.13	0	0.6164	1
15	PCO.15	0	0.5174	1
16	PCO.16	0	0.438	1
18	PCO.18	0	0.4378	1
24	PCO.24	0	0.0549	1

Annex 18 C: See page 310. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using two groups of explanatory variables. The first group comprises the environmental factors s. l., the second group comprises the spatial predictors computed from the XY coordinates. The conditional effects of the groups have been tested. The VIFs within the second group of explanatory variables are shown. The results stem from the un-detrended data.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PCO.1	-0.0387	1.3848	1.2997
3	PCO.3	0.0535	1.1524	1.1108
4	PCO.4	-0.0109	0.9142	1.4545
5	PCO.5	-0.0431	0.9287	3.4549
6	PCO.6	0.0111	0.8723	1.0633
7	PCO.7	0.0078	0.7696	1.3979
8	PCO.8	-0.0031	0.735	1.1182
10	PCO.10	0.0072	0.7695	2.354
14	PCO.14	-0.0079	0.6034	1.1663
15	PCO.15	0.0066	0.5252	1.0252
18	PCO.18	0.0052	0.4491	1.0246

Annex 19 A: See page 311. Variance Inflation Factors from a Variation Partitioning approach based on a CCA using two groups of explanatory variables. The approach is based on the detrended data. The second group comprises the dbMEM computed from the XY coordinates. The conditional effects of the groups have been tested. The VIFs within group two are shown.

Annex 19 B: See page 311. Variance Inflation Factors from a Variation Partitioning approach based on a CCA using two groups of explanatory variables. The approach is based on the detrended data. The first group comprises the environmental factors s. l., the second group comprises the spatial predictors computed from the XY coordinates. The conditional effects of the groups have been tested. The VIFs within group one are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
2	PreciMm	1720.032	312.6447	313.1086
3	ElevS_IM	2329.1263	293.0787	18.9093
4	NEAR_DIS	788.4371	906.7216	58.43
5	throuRoa	0.0578	0.2333	7.1899
6	TreePlnt	0.1298	0.3361	42.2653
7	abv300	0.2764	0.4472	59.6987
8	other	0.0444	0.206	23.0505
9	trghRoEa	0.0427	0.2021	13.0845
10	earRoaTr	0.0845	0.2782	28.2564
11	naroTrTe	0.0547	0.2274	22.9871
12	eRmosTT	0.0638	0.2444	20.2107
13	mosTT	0.0483	0.2144	16.3221
14	Tea	0.025	0.1561	9.7732
15	eaRoTrVi	0.0253	0.157	7.1303
16	erRoTPmo	0.0349	0.1835	13.9863
17	natintEg	0.0256	0.1578	8.5095
18	mosTrPas	0.0208	0.1427	10.4363
19	Uwinka	0.0662	0.2486	0
20	W	0.1405	0.3475	46.9762
21	N	0.2249	0.4175	542.7593
22	C	0.6346	0.4815	0
31	Mg_Al	1.2925	6.009	3.0703
32	HAHFC	0.4374	0.4961	5.0717
33	HAHF	0.0648	0.2462	2.5874
34	DRDL	0.1359	0.3427	2.5689
35	HFFHA	0.0228	0.1493	118.917
36	HCL	0.0221	0.1469	108.469
37	TFH	0.0071	0.0842	1.3198
38	VLVC	0.0435	0.204	7.4625
39	HDC	0.2663	0.442	0
60	C_N	13.8873	2.4792	6.7018
61	PH	3.2238	0.5028	8.9739
64	GraniteS	0.3751	0.4842	36.9608
65	Quarziti	0.225	0.4176	13.6023
66	Sandston	0.0333	0.1795	14.1557
67	SlateMyl	0.1266	0.3325	980.9673
68	GraniteP	0.0669	0.2498	103.0988
69	Volcanic	0.0215	0.1452	8.7564
70	SlatePhy	0.1516	0.3586	0

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PreciMm	1720.032	312.6447	720.5459
2	ElevS_IM	2329.1263	293.0787	60.3221
3	NEAR_DIS	788.4371	906.7216	77.1237
4	throuRoa	0.0578	0.2333	9.8447
5	TreePlnt	0.1298	0.3361	1696.9256
6	abv300	0.2764	0.4472	2979.4493
7	other	0.0444	0.206	606.212
8	trghRoEa	0.0427	0.2021	631.2142
9	earRoaTr	0.0845	0.2782	1171.7014
10	naroTrTe	0.0547	0.2274	766.8918
11	eRmosTT	0.0638	0.2444	896.141
12	mosTT	0.0483	0.2144	681.5475
13	Tea	0.025	0.1561	358.4046
14	eaRoTrVi	0.0253	0.157	375.4297
15	erRoTPmo	0.0349	0.1835	507.525
16	natintEg	0.0256	0.1578	402.5926
17	mosTrPas	0.0208	0.1427	296.7715
18	Uwinka	0.0662	0.2486	0
19	W	0.1405	0.3475	131.6772
20	N	0.2249	0.4175	960.9243
21	C	0.6346	0.4815	0
22	Mg_Al	1.2925	6.009	7.8665
23	HAHFC	0.4374	0.4961	6.3345
24	HAHF	0.0648	0.2462	4.2327
25	DRDL	0.1359	0.3427	3.9305
26	HFFHA	0.0228	0.1493	660.3147
27	HCL	0.0221	0.1469	621.2684
28	TFH	0.0071	0.0842	1.7181
29	VLVC	0.0435	0.204	10.0255
30	HDC	0.2663	0.442	0
31	C_N	13.8873	2.4792	9.3734
32	PH	3.2238	0.5028	11.5607
33	GraniteS	0.3751	0.4842	100.1376
34	Quarziti	0.225	0.4176	58.3279
35	Sandston	0.0333	0.1795	36.7512
36	SlateMyl	0.1266	0.3325	2455.8156
37	GraniteP	0.0669	0.2498	184.537
38	Volcanic	0.0215	0.1452	15.3864
39	SlatePhy	0.1516	0.3586	0
40	PCO.1	-0.0387	1.3848	1608.2662
41	PCO.3	0.0535	1.1524	81.1722
42	PCO.4	-0.0109	0.9142	39.4093
43	PCO.5	-0.0431	0.9287	77.8984
44	PCO.6	0.0111	0.8723	64.0273
45	PCO.7	0.0078	0.7696	13.7364
46	PCO.8	-0.0031	0.735	33.3218
47	PCO.10	0.0072	0.7695	442.1642
48	PCO.14	-0.0079	0.6034	9.6527
49	PCO.15	0.0066	0.5252	6.1609
50	PCO.18	0.0052	0.4491	8.6838

Annex 19 C: See page 311. Variance Inflation Factors from a Variation Partitioning approach based on a CCA using two groups of explanatory variables. The approach is based on the detrended data. The first group comprises the environmental factors s. l., the second group comprises the spatial predictors computed from the XY coordinates. The conditional effects of the groups have been tested. The VIFs within the explanatory variables are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
2	PreciMm	1719.1413	311.8526	282.0757
3	ElevS_IM	2316.8085	296.8281	16.5604
4	NEAR_DIS	772.7827	889.0127	57.9273
5	throuRoa	0.0745	0.2625	9.315
6	TreePlnt	0.1277	0.3337	41.5958
7	abv300	0.2766	0.4473	54.554
8	other	0.0426	0.2018	20.7189
9	trghRoEa	0.0426	0.2018	12.1732
10	earRoaTr	0.0851	0.279	27.1051
11	naroTrTe	0.0532	0.2244	21.9696
12	eRmosTT	0.0532	0.2244	16.8953
13	mosTT	0.0426	0.2018	13.155
14	Tea	0.0213	0.1443	7.7961
15	eaRoTrVi	0.0213	0.1443	7.2665
16	eaRotrTT	0.0213	0.1443	11.9893
17	erRoTPmo	0.0319	0.1758	12.7211
18	natintEg	0.0213	0.1443	6.7314
19	mosTrPas	0.0213	0.1443	9.7612
20	Uwinka	0.0638	0.2444	0
21	W	0.117	0.3214	35.2669
22	N	0.2128	0.4093	496.6561
23	C	0.6702	0.4701	0
33	Mg_Al	2.9103	14.7133	3.269
34	HAHFC	0.4574	0.4982	5.2109
35	HAHF	0.0745	0.2625	3.0251
36	DRDL	0.117	0.3214	2.7558
37	HFFHA	0.0213	0.1443	99.7941
38	HCL	0.0213	0.1443	96.0272
39	TFH	0.0106	0.1026	1.5354
40	VLVC	0.0426	0.2018	7.2555
41	HDC	0.2553	0.436	0
57	clay	0.0957	0.2942	1.8799
58	stone	0.1596	0.3662	2.8816
59	diff	0.0532	0.2244	1.3891
60	loam	0.6915	0.4619	0
63	C_N	13.5966	2.6133	7.1606
64	PH	3.3005	0.5869	10.8844
67	GraniteS	0.3617	0.4805	39.7117
68	Quarziti	0.2128	0.4093	16.122
69	Sandston	0.0319	0.1758	14.8139
70	SlateMyl	0.1489	0.356	1034.5947
71	GraniteP	0.0638	0.2444	92.8621
72	Volcanic	0.0213	0.1443	9.5995
73	SlatePhy	0.1596	0.3662	0

Annex 20 A: See page 315. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using two groups of explanatory variables. The approach is based on the detrended data. The first group comprises the environmental factors s. l., the second group comprises the spatial predictors computed from the XY coordinates. The conditional effects of the groups have been tested. The VIFs within group one are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PreciMm	1719.1413	311.8526	1500.2981
2	ElevS_IM	2316.8085	296.8281	72.3605
3	NEAR_DIS	772.7827	889.0127	116.7065
4	throuRoa	0.0745	0.2625	16.0954
5	TreePlnt	0.1277	0.3337	1275.6033
6	abv300	0.2766	0.4473	2352.6716
7	other	0.0426	0.2018	8047.3671
8	trghRoEa	0.0426	0.2018	452.6882
9	earRoaTr	0.0851	0.279	867.2811
10	naroTrTe	0.0532	0.2244	574.984
11	eRmosTT	0.0532	0.2244	567.2976
12	mosTT	0.0426	0.2018	476.6699
13	Tea	0.0213	0.1443	241.1442
14	eaRoTrVi	0.0213	0.1443	230.7399
15	eaRotrTT	0.0213	0.1443	238.4739
16	erRoTPmo	0.0319	0.1758	344.0397
17	natintEg	0.0213	0.1443	253.0235
18	mosTrPas	0.0213	0.1443	247.478
19	Uwinka	0.0638	0.2444	0
20	W	0.117	0.3214	330.1174
21	N	0.2128	0.4093	1774.6084
22	C	0.6702	0.4701	0
23	Mg_Al	2.9103	14.7133	3.6303
24	HAHFC	0.4574	0.4982	7.3146
25	HAHF	0.0745	0.2625	4.2006
26	DRDL	0.117	0.3214	4.5064
27	HFFHA	0.0213	0.1443	386.8068
28	HCL	0.0213	0.1443	372.8259
29	TFH	0.0106	0.1026	2.288
30	VLVC	0.0426	0.2018	12.2566
31	HDC	0.2553	0.436	0
32	clay	0.0957	0.2942	2.6303
33	stone	0.1596	0.3662	5.233
34	diff	0.0532	0.2244	1.685
35	loam	0.6915	0.4619	0
36	C_N	13.5966	2.6133	13.893
37	PH	3.3005	0.5869	15.9411
38	GraniteS	0.3617	0.4805	129.1928
39	Quarziti	0.2128	0.4093	80.0862
40	Sandston	0.0319	0.1758	38.5341
41	SlateMyl	0.1489	0.356	5558.1486
42	GraniteP	0.0638	0.2444	543.2799
43	Volcanic	0.0213	0.1443	4173.6436
44	SlatePhy	0.1596	0.3662	0
45	PCO.1	0	1.4382	1032.0452
46	PCO.2	0	1.2469	86.3561
47	PCO.3	0	1.1557	98.4266
48	PCO.4	0	1.047	92.4586
49	PCO.5	0	0.9397	68.6102
50	PCO.7	0	0.7805	43.8354
51	PCO.8	0	0.7576	27.2551
52	PCO.11	0	0.6545	50.9318
53	PCO.12	0	0.6489	16.9188
54	PCO.15	0	0.5174	253.1707

Annex 20 B: See page 315. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using two groups of explanatory variables. The approach is based on the detrended data. The first group comprises the environmental factors s. l., the second group comprises the spatial predictors computed from the XY coordinates. The conditional effects of the groups have been tested. The VIFs within the explanatory variables are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
55	PCO.16	0	0.438	44.1794
56	PCO.18	0	0.4378	57.8619
57	PCO.20	0	0.4373	3668.6489
58	PCO.24	0	0.0549	2.1227

Annex 20 B: See page 315. Continued.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PCO.1	0	1.4382	2.9066
2	PCO.2	0	1.2469	13.5444
3	PCO.3	0	1.1557	2.3772
4	PCO.4	0	1.047	2.117
5	PCO.5	0	0.9397	2.2295
7	PCO.7	0	0.7805	5.5465
8	PCO.8	0	0.7576	1.6186
11	PCO.11	0	0.6545	1.1865
12	PCO.12	0	0.6489	1.0581
15	PCO.15	0	0.5174	1.0225
16	PCO.16	0	0.438	1.1344
18	PCO.18	0	0.4378	1.2473
20	PCO.20	0	0.4373	1.3262
24	PCO.24	0	0.0549	1.0006

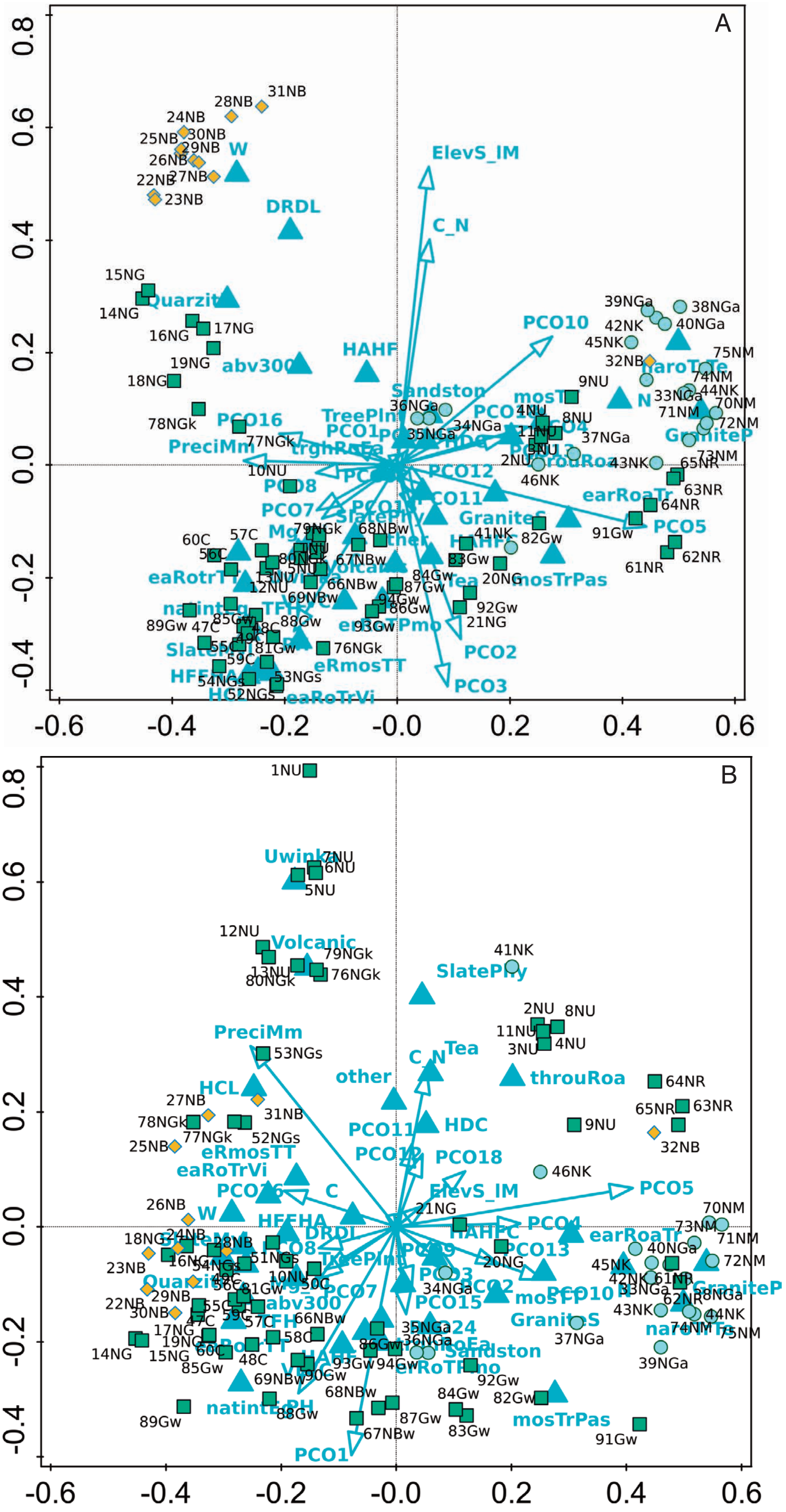
Annex 20 C: See page 315. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using two groups of explanatory variables. The approach is based on the detrended data. The second group comprises the db-MEM computed from the XY coordinates. The conditional effects of the groups have been tested. The VIFs within group two are shown.

Fraction	Variation(adj)	% of Explained	% of All	DF	Mean Square
a	0.05	13.80	5.00	19.00	0.01
b	0.06	17.30	6.30	16.00	0.01
c	0.03	7.70	2.80	16.00	0.01
d	-0.00	-0.60	-0.20	--	--
e	0.044791	12.2	4.5	--	--
f	0.05	13.40	4.90	--	--
g	0.13	36.10	13.20	--	--
Total Explained	0.37	100.00	36.60	51.00	0.01
All Variation	1.00	--	100.00	93.00	--

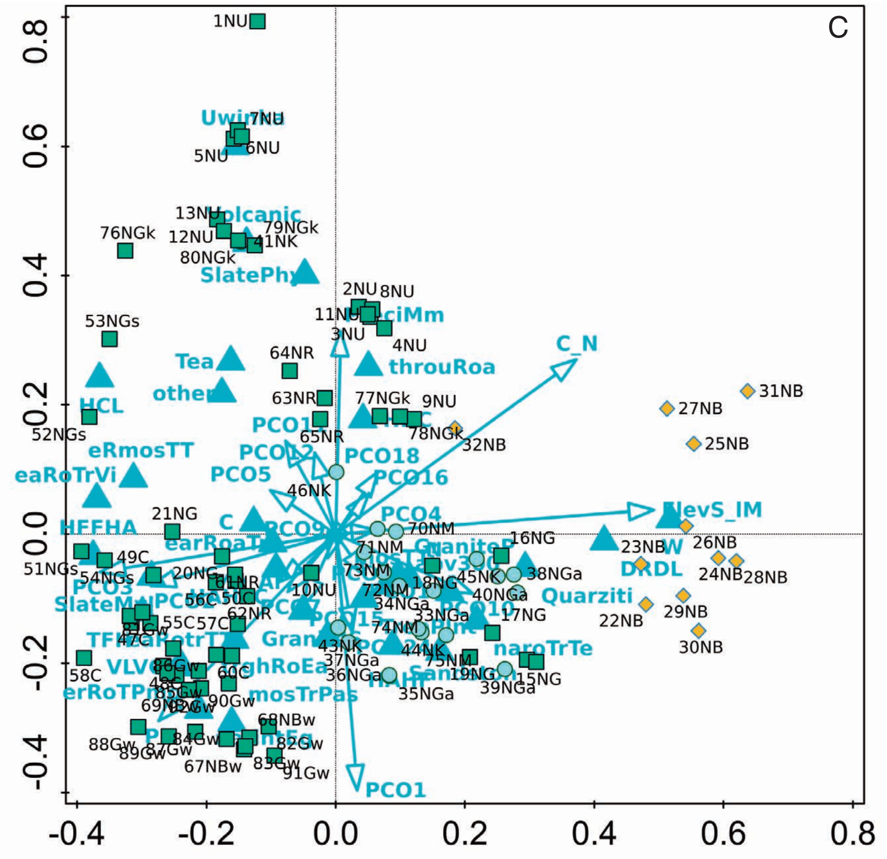
Tested Fraction	F	P
a+b+c+d+e+f+g	2.1	0.001
a+b+d+e+f+g	2.4	0.001
a+c+d+e+f+g	2.2	0.001
b+c+d+e+f+g	2.3	0.001
a+d+f+g	2.5	0.001
b+d+e+g	2.8	0.001
c+e+f+g	3	0.001

Group Members:		
First Group	Second Group	Third Group
Congo_Nile	C_N	PCO.5
Matrix	Cat_Geol	PCO.3
Elev_a_ s_l m	pH	PCO.1
Precip_a mm	Soiltype_FAO	PCO.2
	Mg_Al	PCO.10
		PCO.4
		PCO.18
		PCO.7
		PCO.16
		PCO.8
		PCO.11
		PCO.13
		PCO.24
		PCO.12
		PCO.15
		PCO.9

Annex 21 A: See page 320. Result of a Variation Partitioning approach with interactive forward selection based on a tb-RDA using three groups of explanatory variables. The first group comprises the environmental factors s. str. The second group comprises the soil factors and the third group the spatial predictors computed from the XY coordinates. The simple effects of the groups have been tested. The upper table shows the variation explained per group.



Annex 21 B: See page 320. See page XXV for information.



Annex 21 B: See page 320. Biplots resulting from a Variation Partitioning approach with interactive forward selection based on a tb-RDA using three groups of explanatory variables. Pane A shows axes one and two, pane B axes one and three and pane C axes two and three.

Annex 21 C1: See page 320. VIFs resulting from a Variation Partitioning approach with interactive forward selection based on a tb-RDA using three groups of explanatory variables. The first group comprises the environmental factors s. str. The second group comprises the soil factors and the third group the spatial predictors computed from the XY coordinates. The simple effects of the groups have been tested.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
2	PreciMm	1719.1413	311.8526	1.8115
3	ElevS_IM	2316.8085	296.8281	3.6034
5	throuRoa	0.0745	0.2625	2.0549
6	TreePlnt	0.1277	0.3337	3.0852
7	abv300	0.2766	0.4473	4.8174
8	other	0.0426	0.2018	1.7256
9	trghRoEa	0.0426	0.2018	1.9336
10	earRoaTr	0.0851	0.279	2.2364
11	naroTrTe	0.0532	0.2244	2.474
12	eRmosTT	0.0532	0.2244	2.1309
13	mosTT	0.0426	0.2018	2.1488
14	Tea	0.0213	0.1443	1.5286
15	eaRoTrVi	0.0213	0.1443	1.4322
16	eaRotrTT	0.0213	0.1443	1.5468
17	erRoTPmo	0.0319	0.1758	1.6388
18	natintEg	0.0213	0.1443	1.4894
19	mosTrPas	0.0213	0.1443	1.443
20	Uwinka	0.0638	0.2444	0
21	W	0.117	0.3214	3.317
22	N	0.2128	0.4093	2.6054
23	C	0.6702	0.4701	0

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
10	Mg_Al	2.9103	14.7133	1.7637
11	HAHFC	0.4574	0.4982	2.4342
12	HAHF	0.0745	0.2625	1.6253
13	DRDL	0.117	0.3214	1.8997
14	HFFHA	0.0213	0.1443	1.3232
15	HCL	0.0213	0.1443	1.3423
16	TFH	0.0106	0.1026	1.1567
17	VLVC	0.0426	0.2018	1.6552
18	HDC	0.2553	0.436	0
44	C_N	13.5966	2.6133	3.372
45	PH	3.3005	0.5869	3.5769
48	GraniteS	0.3617	0.4805	3.1891
49	Quarziti	0.2128	0.4093	2.7412
50	Sandston	0.0319	0.1758	1.2402
51	SlateMyl	0.1489	0.356	3.137
52	GraniteP	0.0638	0.2444	1.647
53	Volcanic	0.0213	0.1443	1.2563
54	SlatePhy	0.1596	0.3662	0

Annex 21 C2: See page 320. VIFs resulting from a Variation Partitioning approach with interactive forward selection based on a tb-RDA using three groups of explanatory variables. The first group comprises the environmental factors s. str. The second group comprises the soil factors and the third group the spatial predictors computed from the XY coordinates. The simple effects of the groups have been tested.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PCO1	0	1.4382	8.5199
2	PCO2	0	1.2469	5.9659
3	PCO3	0	1.1557	15.5119
4	PCO4	0	1.047	9.3386
5	PCO5	0	0.9397	3.9985
6	PCO7	0	0.7805	1.764
7	PCO8	0	0.7576	4.8278
8	PCO11	0	0.6545	1.9798
9	PCO12	0	0.6489	1.5167
10	PCO15	0	0.5174	2.2742
11	PCO16	0	0.438	1.9329
12	PCO18	0	0.4378	1.6319
13	PCO20	0	0.4373	1.6997
14	PCO24	0	0.0549	1.3942

Annex 21 C3: See page 320. VIFs resulting from a Variation Partitioning approach with interactive forward selection based on a tb-RDA using three groups of explanatory variables. The first group comprises the environmental factors s. str. The second group comprises the soil factors and the third group the spatial predictors computed from the XY coordinates. The simple effects of the groups have been tested.

Annex 22 A: See page 320. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using three groups of explanatory variables. The conditional effects of the three groups were tested. The first group contains the environmental factors s. str. after refinement via a new forward selection (see above). The second group comprises the soil parameters and the third group the db-MEM computed from the XY coordinates. The VIFs within group one are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PreciMm	1719.1413	311.8526	20.5498
2	ElevS_IM	2316.8085	296.8281	30.4336
3	throuRoa	0.0745	0.2625	3.1317
4	TreePlnt	0.1277	0.3337	397.6415
5	abv300	0.2766	0.4473	711.1162
6	other	0.0426	0.2018	157.1733
7	trghRoEa	0.0426	0.2018	131.7382
8	earRoaTr	0.0851	0.279	259.3511
9	naroTrTe	0.0532	0.2244	172.8708
10	eRmosTT	0.0532	0.2244	178.9118
11	mosTT	0.0426	0.2018	155.0886
12	Tea	0.0213	0.1443	82.3573
13	eaRoTrVi	0.0213	0.1443	71.0766
14	eaRotrTT	0.0213	0.1443	77.6255
15	erRoTPmo	0.0319	0.1758	110.4234
16	natintEg	0.0213	0.1443	78.18
17	mosTrPas	0.0213	0.1443	73.1719
18	Uwinka	0.0638	0.2444	0
19	W	0.117	0.3214	21.4843
20	N	0.2128	0.4093	39.7937
21	C	0.6702	0.4701	0

Annex 22 B: See page 320. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using three groups of explanatory variables. The conditional effects of the three groups were tested. The first group contains the environmental factors s. str. after refinement via a new forward selection (see above). The second group comprises the soil parameters and the third group the db-MEM computed from the XY coordinates. The VIFs within group two are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	Mg_Al	2.9103	14.7133	3.258
2	HAHFC	0.4574	0.4982	3.8686
3	HAHF	0.0745	0.2625	2.8437
4	DRDL	0.117	0.3214	2.7476
5	HFFHA	0.0213	0.1443	2.7011
6	HCL	0.0213	0.1443	2.3522
7	TFH	0.0106	0.1026	1.4343
8	VLVC	0.0426	0.2018	6.4402
9	HDC	0.2553	0.436	0
10	clay	0.0957	0.2942	1.8214
11	stone	0.1596	0.3662	2.7196
12	diff	0.0532	0.2244	1.3061
13	loam	0.6915	0.4619	0
14	C_N	13.5966	2.6133	6.6331
15	PH	3.3005	0.5869	10.699
16	GraniteS	0.3617	0.4805	25.9318
17	Quarziti	0.2128	0.4093	14.0204
18	Sandston	0.0319	0.1758	9.4277
19	SlateMyl	0.1489	0.356	15.5207
20	GraniteP	0.0638	0.2444	10.1097
21	Volcanic	0.0213	0.1443	4.4196
22	SlatePhy	0.1596	0.3662	0

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PCO1	0	1.4382	8.5199
2	PCO2	0	1.2469	5.9659
3	PCO3	0	1.1557	15.5119
4	PCO4	0	1.047	9.3386
5	PCO5	0	0.9397	3.9985
6	PCO7	0	0.7805	1.764
7	PCO8	0	0.7576	4.8278
8	PCO11	0	0.6545	1.9798
9	PCO12	0	0.6489	1.5167
10	PCO15	0	0.5174	2.2742
11	PCO16	0	0.438	1.9329
12	PCO18	0	0.4378	1.6319
13	PCO20	0	0.4373	1.6997
14	PCO24	0	0.0549	1.3942

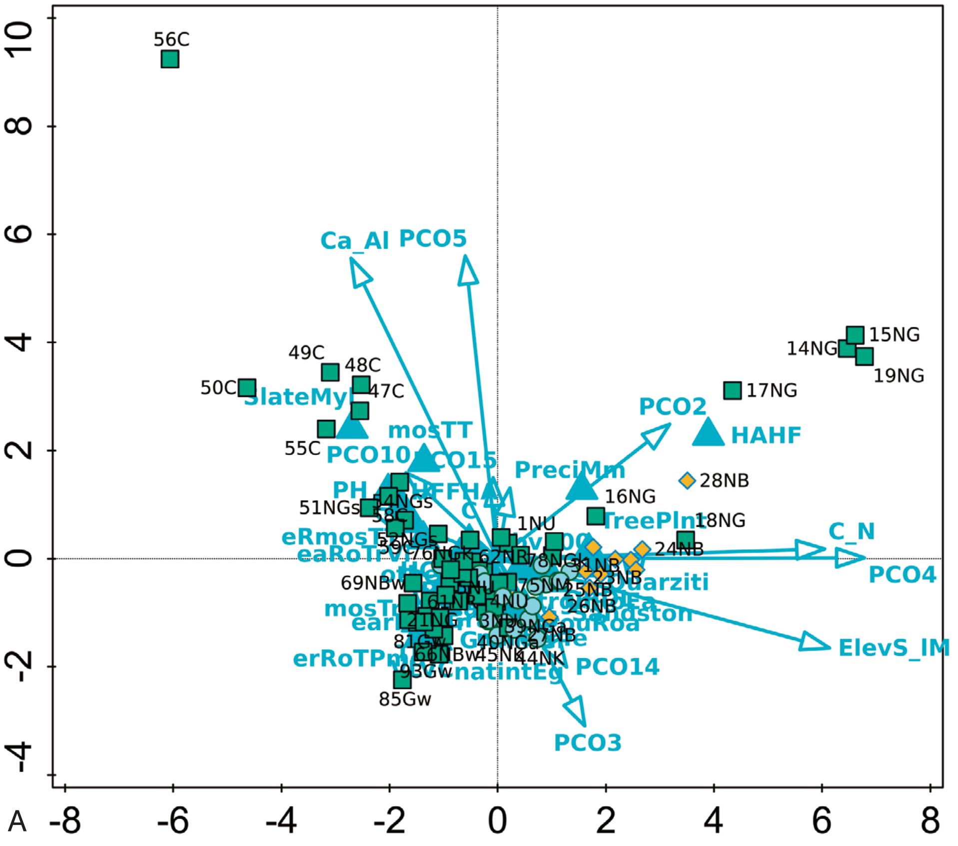
Annex 22 C: See page 320. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using three groups of explanatory variables. The conditional effects of the three groups were tested. The first group contains the environmental factors s. str. after refinement via a new forward selection (see above). The second group comprises the soil parameters and the third group the db-MEM computed from the XY coordinates. The VIFs within group three are shown.

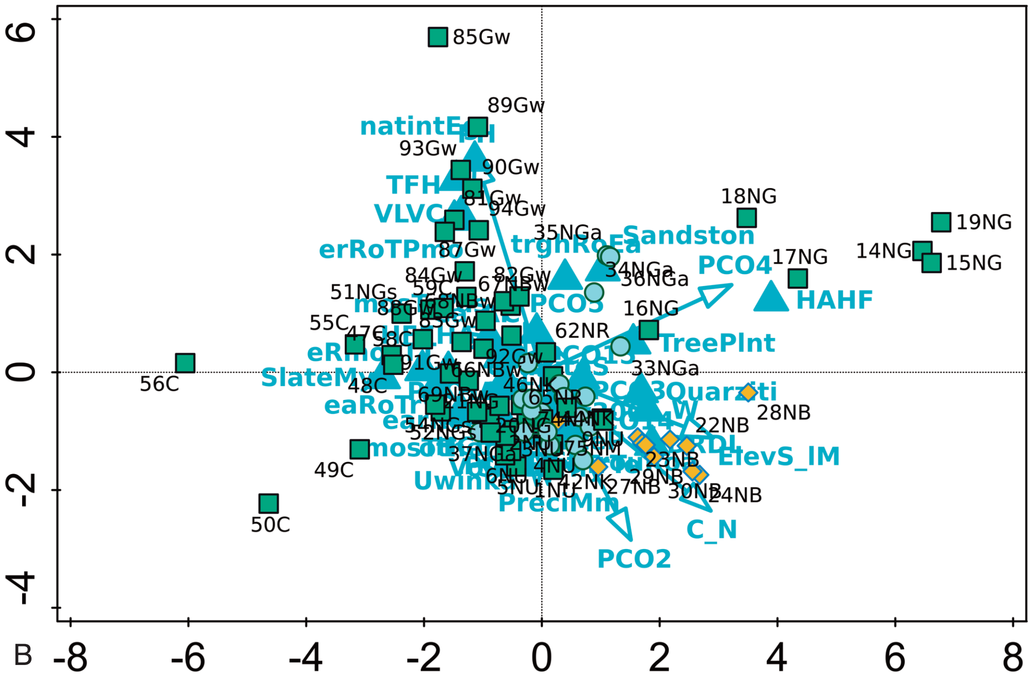
Fraction	Variation(adj)	% of Explained	% of All	DF	Mean Square
a	0.86	20.10	4.40	18.00	0.21
b	1.57	36.70	8.00	16.00	0.24
c	0.30	7.00	1.50	8.00	0.19
d	-0.06	-1.30	-0.30	--	--
e	**0.50358**	**11.7**	**2.6**	--	--
f	0.28	6.60	1.40	--	--
g	0.82	19.20	4.20	--	--
Total Explained	4.29	100.00	21.70	42.00	0.27
All Variation	19.74	--	100.00	90.00	--

Tested Fraction	F	P
a+b+c+d+e+f+g	1.6	0.001
a+b+d+e+f+g	1.7	0.001
a+c+d+e+f+g	1.6	0.001
b+c+d+e+f+g	1.8	0.001
a+d+f+g	1.5	0.001
b+d+e+g	1.9	0.001
c+e+f+g	2.2	0.001

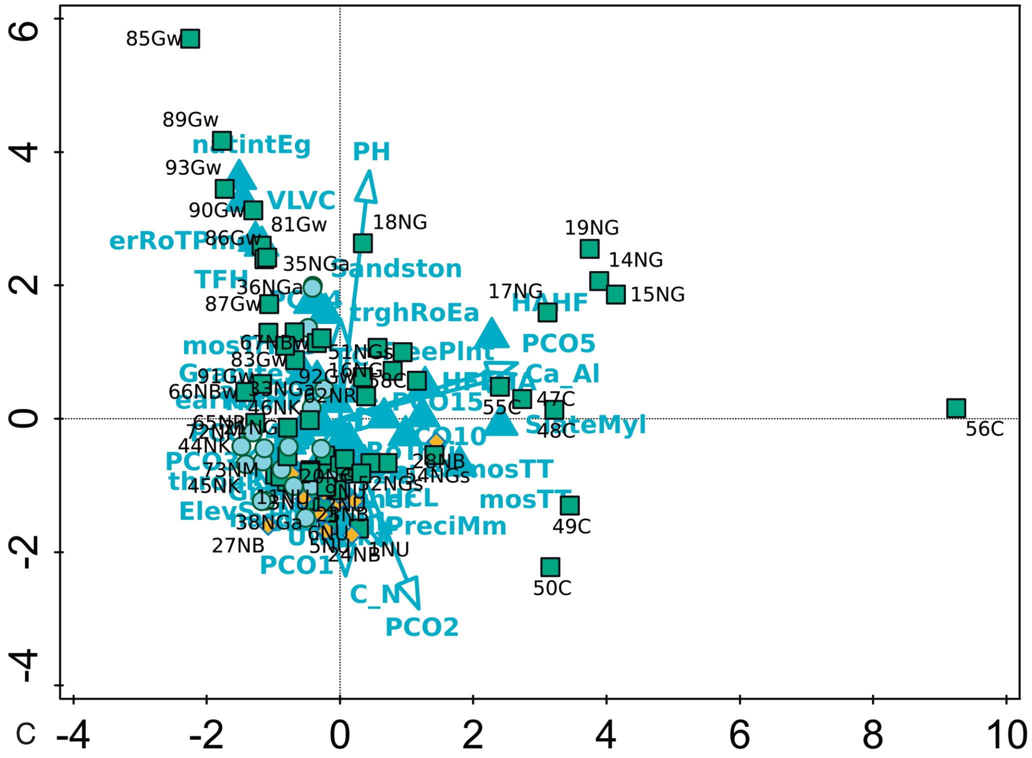
Group Members:		
First Group	Second Group	Third Group
Elev_a_ s_l m	C_N	PCO.4
Precip_a mm	pH	PCO.2
Matrix	Cat_Geol	PCO.3
Congo_Nile	Ca_Al	PCO.5
	Soiltype_FAO	PCO.1
		PCO.14
		PCO.10
		PCO.15

Annex 23 A: See page 324. Result of a Variation Partitioning approach with interactive forward selection based on a CCA using three groups of explanatory variables. The first group comprises the environmental factors s. str. The second group comprises the soil factors and the third group the spatial predictors computed from the XY coordinates. The simple effects of the groups have been tested. The upper table shows the variation explained per group.





Annex 23 B: See page 324. Biplots resulting from a Variation Partitioning approach with interactive forward selection based on a CCA using three groups of explanatory variables. The simple effects of the groups of explanatory variables were tested. Pane A shows axes one and two, pane B axes one and three and pane C axes two and three.



Annex 23 B: See page 324. Biplots resulting from a Variation Partitioning approach with interactive forward selection based on a CCA using three groups of explanatory variables. The simple effects of the groups of explanatory variables were tested. Pane A shows axes one and two, pane B axes one and three and pane C axes two and three.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	ElevS_IM	2329.1263	293.0787	4.2191
2	PreciMm	1720.032	312.6447	1.8921
3	throuRoa	0.0578	0.2333	1.8119
4	TreePlnt	0.1298	0.3361	3.0624
5	abv300	0.2764	0.4472	5.0938
6	other	0.0444	0.206	1.7532
7	trghRoEa	0.0427	0.2021	1.9333
8	earRoaTr	0.0845	0.2782	2.1987
9	naroTrTe	0.0547	0.2274	2.4688
10	eRmosTT	0.0638	0.2444	2.366
11	mosTT	0.0483	0.2144	2.3119
12	Tea	0.025	0.1561	1.6353
13	eaRoTrVi	0.0253	0.157	1.5288
14	erRoTPmo	0.0349	0.1835	1.6909
15	natintEg	0.0256	0.1578	1.5937
16	mosTrPas	0.0208	0.1427	1.4304
17	Uwinka	0.0662	0.2486	0
18	W	0.1405	0.3475	4.3494
19	N	0.2249	0.4175	2.8048
20	C	0.6346	0.4815	0

Annex 23 C1: See page 324. Variance Inflation Factors from a Variation Partitioning approach based on a CCA using three groups of explanatory variables. The conditional effects of the three groups were tested. The first group contains the environmental factors s. str. after refinement via a new forward selection (see above). The second group comprises the soil parameters and the third group the db-MEM computed from the XY coordinates. The VIFs within group one are shown.

Annex 23 C2: See page 324. Variance Inflation Factors from a Variation Partitioning approach based on a CCA using three groups of explanatory variables. The conditional effects of the three groups were tested. The first group contains the environmental factors s. str. after refinement via a new forward selection (see above). The second group comprises the soil parameters and the third group the db-MEM computed from the XY coordinates. The VIFs within group two are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	C_N	13.8873	2.4792	3.4678
2	PH	3.2238	0.5028	3.1451
3	GraniteS	0.3751	0.4842	3.2479
4	Quarziti	0.225	0.4176	2.8672
5	Sandston	0.0333	0.1795	1.2667
6	SlateMyl	0.1266	0.3325	3.2424
7	GraniteP	0.0669	0.2498	1.6767
8	Volcanic	0.0215	0.1452	1.2768
9	SlatePhy	0.1516	0.3586	0
10	Ca_Al	14.0263	57.0493	1.4721
11	HAHFC	0.4374	0.4961	2.4178
12	HAHF	0.0648	0.2462	1.5336
13	DRDL	0.1359	0.3427	1.9952
14	HFFHA	0.0228	0.1493	1.3782
15	HCL	0.0221	0.1469	1.3968
16	TFH	0.0071	0.0842	1.1098
17	VLVC	0.0435	0.204	1.6831
18	HDC	0.2663	0.442	0

Annex 23 C3: See page 324. Variance Inflation Factors from a Variation Partitioning approach based on a CCA using three groups of explanatory variables. The conditional effects of the three groups were tested. The first group contains the environmental factors s. str. after refinement via a new forward selection (see above). The second group comprises the soil parameters and the third group the db-MEM computed from the XY coordinates. The VIFs within group three are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PCO4	-0.0109	0.9142	1.0025
2	PCO2	0.0199	1.2914	1.0025
3	PCO3	0.0535	1.1524	1.0082
4	PCO5	-0.0431	0.9287	1.0072
5	PCO1	-0.0387	1.3848	1.0012
6	PCO14	-0.0079	0.6034	1.0035
7	PCO10	0.0072	0.7695	1.0001
8	PCO15	0.0066	0.5252	1.0005

Annex 24 A: See page 324. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using three groups of explanatory variables. The conditional effects of the three groups were tested. The first group contains the environmental factors s. str. after refinement via a new forward selection (see above). The second group comprises the soil parameters and the third group the db-MEM computed from the XY coordinates. The VIFs within group one are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PreciMm	1720.032	312.6447	3.8197
2	ElevS_IM	2329.1263	293.0787	19.3423
3	throuRoa	0.0578	0.2333	1.9812
4	TreePlnt	0.1298	0.3361	10.1644
5	abv300	0.2764	0.4472	8.3533
6	other	0.0444	0.206	2.2722
7	trghRoEa	0.0427	0.2021	4.2256
8	earRoaTr	0.0845	0.2782	3.168
9	naroTrTe	0.0547	0.2274	5.3809
10	eRmosTT	0.0638	0.2444	4.8572
11	mosTT	0.0483	0.2144	4.4451
12	Tea	0.025	0.1561	2.3815
13	eaRoTrVi	0.0253	0.157	2.7076
14	erRoTPmo	0.0349	0.1835	2.1378
15	natintEg	0.0256	0.1578	2.2844
16	mosTrPas	0.0208	0.1427	1.7304
17	Uwinka	0.0662	0.2486	0
18	W	0.1405	0.3475	16.8301
19	N	0.2249	0.4175	24.3658
20	C	0.6346	0.4815	0

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	Ca_Al	14.0263	57.0493	2.3469
2	Mg_Al	1.2925	6.009	3.2527
3	HAHFC	0.4374	0.4961	4.2391
4	HAHF	0.0648	0.2462	2.405
5	DRDL	0.1359	0.3427	2.7166
6	HFFHA	0.0228	0.1493	3.3051
7	HCL	0.0221	0.1469	2.3528
8	TFH	0.0071	0.0842	1.2756
9	VLVC	0.0435	0.204	6.5795
10	HDC	0.2663	0.442	0
11	C_N	13.8873	2.4792	6.5922
12	PH	3.2238	0.5028	9.5102
13	GraniteS	0.3751	0.4842	23.8549
14	Quarziti	0.225	0.4176	12.0359
15	Sandston	0.0333	0.1795	9.8634
16	SlateMyl	0.1266	0.3325	12.4517
17	GraniteP	0.0669	0.2498	10.3859
18	Volcanic	0.0215	0.1452	4.0482
19	SlatePhy	0.1516	0.3586	0

Annex 24 B: See page 324. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using three groups of explanatory variables. The conditional effects of the three groups were tested. The first group contains the environmental factors s. str. after refinement via a new forward selection (see above). The second group comprises the soil parameters and the third group the db-MEM computed from the XY coordinates. The VIFs within group two are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PCO3	0.0535	1.1524	7.9509
2	PCO4	-0.0109	0.9142	18.7746
3	PCO5	-0.0431	0.9287	20.3032
4	PCO6	0.0111	0.8723	7.6164
5	PCO7	0.0078	0.7696	2.327
6	PCO8	-0.003	0.735	5.42
7	PCO10	0.0072	0.7695	21.6004
8	PCO14	-0.0079	0.6034	9.342
9	PCO15	0.0066	0.5252	3.1835
10	PCO18	0.0052	0.4491	1.513

Annex 24 C: See page 324. Variance Inflation Factors from a Variation Partitioning approach based on a tb-RDA using three groups of explanatory variables. The conditional effects of the three groups were tested. The first group contains the environmental factors s. str. after refinement via a new forward selection (see above). The second group comprises the soil parameters and the third group the db-MEM computed from the XY coordinates. The VIFs within group three are shown.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PCO.1	0	1.4154	8.3392
2	PCO.2	0	1.2612	29.5071
3	PCO.3	0	1.1291	5.2963
4	PCO.4	0	0.9794	6.1439
5	PCO.5	0	0.9337	20.5552
6	PCO.6	0	0.8626	1.3873
7	PCO.7	0	0.7932	14.0334
8	PCO.8	0	0.77	3.3679
9	PCO.9	0	0.768	1.7488
10	PCO.10	0	0.7637	11.6894
11	PCO.11	0	0.6639	4.327
12	PCO.12	0	0.6265	2.2177
14	PCO.14	0	0.5819	2.3731
15	PCO.15	0	0.521	1.1081
16	PCO.16	0	0.4451	2.1358
17	PCO.17	0	0.4451	2.0686
20	PCO.20	0	0.4444	1.8832
21	PCO.21	0	0.3436	2.4172

Annex 25: See page 328. Variance Inflation Factors resulting from an RDA using the environmental factors s. l. as response variables and dbMEM computed from the XY coordinates as independent variables. The spatial predictors stem from an approach that required the exclusion of three samples. The VIFs given stem from the detrended data.

Annex 26: See page 332. Variance Inflation Factors resulting from an RDA using the environmental factors s. l. as response variables and dbMEM computed from the XY coordinates as independent variables. The spatial predictors stem from an approach that required the exclusion of three samples. The VIFs given stem from the detrended data and represent the broad scale.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PCO.1	0	1.4154	1.2489
3	PCO.3	0	1.1291	1.1248
4	PCO.4	0	0.9794	1.2422
5	PCO.5	0	0.9337	1.9302
6	PCO.6	0	0.8626	1.0198
7	PCO.7	0	0.7932	1.3685

Annex 27: See page 333. Variance Inflation Factors resulting from an RDA using the environmental factors s. l. as response variables and dbMEM computed from the XY coordinates as independent variables. The spatial predictors stem from an approach that required the exclusion of three samples. The VIFs given stem from the detrended data and represent the medium scale.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
8	PCO.8	0	0.77	1.0464
10	PCO.10	0	0.7637	1.3223

Annex 28: See page 335. Variance Inflation Factors resulting from an RDA using the environmental factors s. l. as response variables and dbMEM computed from the XY coordinates as independent variables. The spatial predictors stem from an approach that includeded of all the samples.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PCO.1	0	1.4382	1.2501
3	PCO.3	0	1.1557	5.2375
4	PCO.4	0	1.047	12.6596
5	PCO.5	0	0.9397	5.998
6	PCO.6	0	0.8541	1.0649
7	PCO.7	0	0.7805	2.2166
8	PCO.8	0	0.7576	1.7049
9	PCO.9	0	0.7556	1.0302
10	PCO.10	0	0.7514	9.0148
11	PCO.11	0	0.6545	2.9743
12	PCO.12	0	0.6489	1.3937
13	PCO.13	0	0.6164	1.8599
16	PCO.16	0	0.438	1.7277
17	PCO.17	0	0.438	1.7955
20	PCO.20	0	0.4373	1.051
21	PCO.21	0	0.3381	1.0437

Annex 29: See page 337. Variance Inflation Factors resulting from an RDA using the environmental factors s. l. as response variables and dbMEM computed from the XY coordinates as independent variables. The spatial predictors stem from an approach that includeded of all the samples. The VIFs given stem from the detrended data and represent the broad scale.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
1	PCO.1	0	1.4382	1.1153
3	PCO.3	0	1.1557	1.3641
4	PCO.4	0	1.047	1.7651
5	PCO.5	0	0.9397	1.3348

Annex 30: See page 337. Variance Inflation Factors resulting from an RDA using the environmental factors s. l. as response variables and dbMEM computed from the XY coordinates as independent variables. The spatial predictors stem from an approach that includeded of all the samples. The VIFs given stem from the detrended data and represent the medium scale.

N	Name	(weighted) Mean	Stand. Dev.	Inflation Factor
7	PCO.7	0	0.7805	1.2775
8	PCO.8	0	0.7576	1.0519
11	PCO.11	0	0.6545	1.0612
12	PCO.12	0	0.6489	1.0134

Species List

Piperaceae Giseke	*Piper capense* L. f. *Piper* cf. *capense* L. f. *Peperomia fernandopoiana* C.DC.
Hernandiaceae Blume	*Illigera pentaphylla* Welw. *Illigera* cf. *pentaphylla* Welw.
Lauraceae Juss.	*Beilschmiedia rwandensis* R. Wilczek *Ocotea usambarensis* Engl. *Ocotea* cf. *usambarensis* Engl. *Persea americana* Mill.
Monimiaceae Juss.	*Xymalos monospora* (Harv.) Baill. ex Warb. cf. *Xymalos monospora* (Harv.) Baill. ex Warb.
Annonaceae Juss.	*Monanthotaxis orophila* (Boutique) Verdc. cf. *Monanthotaxis orophila* (Boutique) Verdc.
Araceae Juss.	*Culcasia falcifolia* Engl. *Culcasia scandens* P. Beauv.
Colchicaceae DC.	*Gloriosa superba* L. var. *superba*
Smilacaceae Vent.	*Smilax anceps* Willd.
Amaryllidaceae J. St.-Hil.	*Scadoxus multiflorus* (Martyn) Raf.
Asparagaceae Juss.	*Asparagus asparagoides* (L.) Druce *Dracaena afromontana* Mildbr. *Dracaena fragrans* (L.) Ker Gawl. *Dracaena laxissima* Engl. *Chlorophytum comosum* (Thunb.) Jacques *Chlorophytum* cf. *comosum* (Thunb.) Jacques
Iridaceae Juss.	cf. *Gladiolus dalenii* Van Geel
Orchidaceae Juss.	*Bulbophyllum cochleatum* Lindl. *Bulbophyllum* cf. *cochleatum* Lindl. *Bulbophyllum* cf. *kivuense* J.J. Verm. *Liparis bowkeri* Harv. *Polystachya leonardiana* Geerinck *Rhipidoglossum bilobatum* (Summerh.) Szlach. & Olszewski *Tridactyle* sp. Schltr.
Commelinaceae Mirb.	*Commelinaceae* sp. Mirb. *Aneilema* aff. *spekei* C.B. Clarke *Aneilema aequinoctiale* (P.Beauv) G.Don *Cyanotis vaga* (Lour.) Schult. & Schult. f. cf. *Cyanotis vaga* (Lour.) Schult. & Schult. f. *Palisota mannii* C.B. Clarke
Cyperaceae Juss.	*Cyperus renschii* Boeckeler *Cyperus* subgen. *Mariscus* (Vahl) C.B. Clarke *Carex* cf. *conferta* Hochst. ex A. Rich. *Carex spicatopaniculata* Boeckeler ex C.B. Clarke *Scleria distans* Poir.

Poaceae Branhart	*Aristida adoensis* Hochst.
	cf. *Aristida adoensis* Hochst.
	Eragrostis mollior Pilg. ex R.E. Fr.
	Isachne mauritiana Kunth
	cf. *Isachne mauritiana* Kunth
	Adenochloa adenophora (K. Schum.) Zuloaga
	Adenochloa squarrosa (Peter) Zuloaga
	Adenochloa claytonii (Renvoize) Zuloaga
	Adenochloa cf. *claytonii* (Renvoize) Zuloaga
	Oplismenus hirtellus (L.) P. Beauv.
	Dichanthelium hillebrandianum (C.L. Hitchc.) C.A. Clark & Gould
	Dichanthelium cf. *hillebrandianum* (C.L. Hitchc.) C.A. Clark & Gould
	Poecilostachys oplismenoides (Hack.) Clayton
	Setaria megaphylla (Steud.) T. Durand & Schinz
	cf. *Poa leptoclada* Hochst. ex A.Rich.
Zingiberaceae Martinov	*Aframomum* cf. *mala* (K. Schum.) K. Schum
Menispermaceae Juss.	*Stephania abyssinica* (quart.-Dill. & A. Rich) Walp.
	Stephania cf. *abyssinica* (quart.-Dill. & A. Rich) Walp.
	Stephania cyanantha Welw. ex Hiern
	Stephania cf. *cyanantha* Welw. ex Hiern
	Tiliacora funifera (Miers.) Oliv.
Ranunculaceae Juss.	*Clematis simensis* Fresen.
	Clematis cf. *simensis* Fresen.
	Clematis cf. *grandiflora* DC.
	Thalictrum rhynchocarpum Quart.-Dill. & A. Rich.
Proteaceae Juss.	*Faurea saligna* Harvey
Crassulaceae J. St.-Hil.	*Kalanchoe crenata* (Andrews) Haw.
Vitaceae Juss.	*Cyphostemma bambuseti* (Gilg & M. Brandt) Desc. ex Wild & R.B.
Drumm.	
	Cissus oliveri (Engl.) Gilg
	Cissus cf. *oliveri* (Engl.) Gilg
Fabaceae Lindl.	*Albizia gummifera* (J.F. Gmel.) C.A. Sm.
	Senegalia montigena (Brenan & Exell) Kyal. & Boatwr.
	Newtonia buchananii (Baker f.) G.C.C. Gilbert & Boutique
	Dalbergia lactea Vatke
	Dalbergia cf. *lactea* Vatke
	Kotschya aeschynomenoides (Baker) De Wit. & Duvign.
	Grona cf. *ramosissima* (G. Don) H. Ohashi & K. Ohashi
	Hylodesmum repandum (Vahl) H. Ohashi & K. Ohashi
	Parochetus communis Buch.-Ham. ex D. Don
Polygalaceae Hoffmanns. & Link	*Polygala engleri* Chodat
	Polygala ruwenzoriensis Chodat
Cannabaceae Martinov	*Celtis durandii* Engl.
	Celtis gomphophylla Baker
	Celtis cf. *gomphophylla* Baker
	cf. *Celtis gomphophylla* Baker
Moraceae Gaudich.	*Ficus asperifolia* Miq.
	Ficus natalensis Hochst.
	Ficus aff. *natalensis* Hochst.
	Ficus ottonifolia (Miq.) Miq.
	Ficus cf. *ottonifolia* (Miq.) Miq.
	Ficus sur Forssk.

Rhamnaceae Juss.	*Gouania longispicata* Engl.
	Gouania cf. longispicata Engl.
	Maesopsis eminii Engl.
Rosaceae Juss.	*Hagenia abyssinica* (Bruce) J.F. Gmelin
	Alchemilla kiwuensis Engl.
	*Rubus apetalu*s Poir.
	Rubus cf. *apetalus* Poir.
	Rubus pinnatus Willd.
	Rubus cf. *pinnatus* Willd.
	Rubus rigidus Sm.
	Rubus steudneri Schweinf.
	Rubus cf. *steudneri* Schweinf.
	Prunus africana (Hook. f.) Kalkm.
Urticaceae Juss.	*Boehmeria* cf. *virgata* ssp. *macrophylla* (Hornem.) Friis & Wilmot-Dear
	Girardinia bullosa Wedd.
	Laportea alatipes Hook. f.
	Musanga leo-errerae Hauman & Léonard
	Urera hypselodendron (Hochst. Ex A. Rich.) Wedd
	Urera trinervis (Hochst.) Friis & Immelman
	Elatostema monticola Hook. f.
	Pilea bambuseti Engl.
	Pilea cf. *bambuseti* Engl.
	cf. *Pilea bambuseti* Engl.
	Pilea rivularis Wedd.
	Pilea cf. *rivularis* Wedd. var. rivularis
	Pilea johnstonii Oliv.
	Pilea cf. *johnstonii* Oliv.
	cf. *Pilea johnstonii* Oliv.
	Myrianthus holstii Engl.
	cf. *Myrianthus holstii* Engl.
Myricaceae Rich. ex Kunth	*Myrica salicifolia* Hochst. ex A. Rich.
Begoniaceae C. Agardh	*Begonia* meyeri-johannis Engl.
Cucurbitaceae Juss.	Gen. nov. sp. nov.
	Peponium vogelii (Hook. f.) Engl.
	Coccinia mildbraedii Harms
	Coccinia cf. *mildbraedii* Harms
	Oreosyce africana Hook f.
	Momordica cissoides Benth.
	Momordica foetida Schumach.
	Momordica cf. *friesiorum* Harms C. Jeffrey
Celastraceae R. Br.	*Salacia erecta* (G.Don.) Walp
	Elaeodendron cf. *buchananii* (Loes.) Loes.
	Maytenus acuminata (L. f) Loes.
	Gymnosporia heterophylla (Eckl. & Zeyh.) Loes.
	Loeseneriella africana (Willd.) R. Wilczek
Connaraceae R. Br.	*Agelaea pentagyna* (Lam.) Baill.
	Rourea thomsonii (Baker) Jongkind
	cf. *Rourea thomsonii* (Baker) Jongkind
Achariaceae Harms	*Lindackeria bukobensis* Gilg
Chrysobalanaceae R. Br.	*Magnistipula butayei* De Wild.
	Parinari excellsa Sabine

Clusiaceae Lindl.	*Garcinia volkensii* Engl. *Pentadesma reyndersii* Spirlet *Symphonia globulifera* L. f.
Euphorbiaceae Juss.	*Alchornea hirtella* Benth. *Acalypha manniana* Müll. Arg. *Acalypha ornata* Hochst. ex A. Rich. *Acalypha volkensii* Pax *Erythrococca atrovirens* (Pax) Prain *Erythrococca* cf. *atrovirens* (Pax) Prain *Macaranga kilimandscharica* (Pax) Friis & M.G. Gilbert *Neoboutonia macrocalyx* Pax *Croton macrostachyus* Hochst. ex Delile *Croton* cf. *macrostachyus* Hochst. ex Delile *Croton megalocarpus* Hutch. *Shirakiopsis elliptica* (Hochst.) Esser cf. *Shirakiopsis elliptica* (Hochst.) Esser
Peraceae Klotzsch	*Clutia abyssinica* Jaub. & Spach cf. *Clutia abyssinica* Jaub. & Spach
Hypericaceae Juss.	*Harungana montana* Spirlet *Harungana* cf. *montana* Spirlet *Hypericum revolutum* Vahl *Hypericum* cf. *revolutum* Vahl
Ochnaceae DC.	*Ochna afzelii* R. Br. ex Oliv.
Passifloraceae Juss. ex Roussel	*Adenia bequaertii* Robyns & Lawalrée *Adenia* cf. *bequaertii* Robyns & Lawalrée
Phyllanthaceae Martinov	*Bridelia brideliifolia* (Pax) Fedde *Cleistanthus polystachyus* Hook. f. ex Planch *Phyllanthus nummularifolius* Poiret *Phyllanthus ovalifolius* Forssk.
Putranjivaceae Endl.	*Drypetes gerrardii* Hutch.
Rhizophoraceae Pers.	*Cassipourea ruwensorensis* Alston *Cassipourea ndando* J. Léonard ex Floret
Salicaceae Mirb.	*Casearia runssorica* Gilg
Violaceae Batsch	*Rinorea angustifolia* ssp. engleriana (De Wild. & T. Durand) Grey-Wilson *Viola abyssinica* Steud. ex Oliv.
Geraniaceae Juss.	*Geranium arabicum* Forssk.
Francoaceae A.Juss.	*Bersama abyssinica* Fresen. *Bersama abyssinica* var. *engleriana* (Gürke) Verdc.
Melastomataceae Juss.	*Dichaetanthera corymbosa* Jacq.-Fél. *Dupineta* cf. *brazzae* (Cogn.) Ver.-Lib. & G. Kadereit *Cincinnobotrys speciosa* (A. Fern. & R. Fern.) Jacq.-Fél. *Warneckea walikalensis* (A. Fern. & R. Fern.) Jacq.-Fél.
Myrtaceae Juss.	*Syzygium parvifolium* (Engl.) Mildbr.
Penaeaceae Sweet ex Guill.	*Olinia rochetiana* A.Jus.
Anacardiaceae R. Br.	*Pseudospondias microcarpa* (A. Rich.) Engl.

Meliaceae Juss.	*Carapa grandiflora* Sprague
	Carapa sp. nov.
	Entandrophragma excelsum (Dawe & Sprague) Sprague
	Ekebergia capensis Sparrm.
	Lepidotrichilia volkensii (Gürke) J.-F. Leroy ex Styles & F. White
Rutaceae Juss.	*Clausena anisata* (Willd.) Hook. f. ex Benth.
	Toddalia asiatica (L.) Lam.
	Vepris nobilis (Delile) Mziray
	Zanthoxylum gilletii (De Wild.) P. G. Waterman
	Zanthoxylum cf. *mildbraedii* (Engl.) P.G. Waterman
Sapindaceae Juss.	*Lepisanthes senegalensis* (Juss. ex Poir.) Leehn.
	Pancovia golungensis (Hiern.) Exell & Mendoça
	Deinbollia kilimandscharica Taub.
	Allophylus abyssinicus (Hochst.) Radlk.
	Allophylus chaunostachys Gilg
	Allophylus pseudopaniculatus Baker f.
	Allophylus cf. *pseudopaniculatus* Baker f.
Capparaceae Juss.	*Ritchiea albersii* Gilg
Malvaceae Juss.	*Dombeya* cf. *rotundifolia* (Hochst.) Planch.
	Dombeya torrida (J.F. Gmel.) Bamps
	Triumfetta cordifolia A. Rich.
	Microcos mildbraedii (Burret) Burret
	Pavonia kilimandscharica Gürke
	Sida ternata L. f.
	Cola pierlotii R. Germ.
	cf. *Cola pierlotii* R. Germ.
Thymelaeaceae Juss.	*Peddiea fischeri* Engl.
	Peddiea orophila A. Robyns
	Peddiea cf. *rapaneoides* Gilg ex Engl.
	Struthiola thomsonii Oliv.
Strombosiaceae Tiegh.	*Strombosia scheffleri* Engl.
Amaranthaceae Juss.	*Celosia elegantissima* Hauman
	cf. *Celosia elegantissima* Hauman
	Sericostachys scandens Gilg & Lopr ex Lopr.
	Achyranthes aspera
Basellaceae Raf.	*Basella alba* L.
Caryophllyaceae Juss.	*Stellaria mannii* Hook. f.
	Stellaria sennii Chiov.
	cf. *Stellaria mannii* Hook. f.
	cf. *Lychnis kiwuensis* (T.C.E. Fries) M. Popp
	Drymaria cordata (L.) Willd. ex Roem. & Schult.
	Drymaria cf. *cordata* (L.) Willd. ex Roem. & Schult.
Polygonaceae Juss.	*Harpagocarpus snowdenii* Hutch. & Dandy
	Rumex cf. *abyssinicus* Jacq.
Cornaceae Bercht. ex J. Presl.	*Alangium chinense* (Lour.) Harms
Balsaminaceae A. Rich.	*Impatiens burtonii* Hook. f.
	Impatiens cf. *burtonii* Hook. f.
	Impatiens cf. *erecticornis* Wilczek & Schulze
	Impatiens gesneroidea Gilg

Balsaminaceae A. Rich.	*Impatiens nyungwensis Eb. Fisch., Dhetchuvi & Ntaganda*
	Impatiens niamniamensis Gilg
	Impatiens purpureo-violacea Gilg
	Impatiens purpureo-violacea s. l. Gilg
	Impatiens stuhlmannii Warb.
	Impatiens cf. *warburgiana* Wilczek & Schulze
Ebenaceae Gürke	*Diospyros gabunensis* Gürke
Ericaceae Juss.	*Erica mannii* (Hook F.) Beentje
	Erica kingaensis Engl.
	Agarista salicifolia (Lam.) G. Don
	Vaccinium stanleyi Schweinf.
	cf. *Vaccinium stanleyi* Schweinf.
Theaceae Mirb. ex Ker Gawl.	*Balthasaria schliebenii* (Melch.) Verdc.
Primulaceae Batsch ex Borkh.	*Embelia libeniana* Taton
	Embelia schimperi Vatke
	Ardisiandra wettsteinii R. Wagner
	cf. Ardisiandra wettsteinii R. Wagner
	Myrsine melanophloeos (L.) R.Br. ex Sweet
	Myrsine cf. *melanophloeos* (L.) R.Br. ex Sweet
	Maesa lanceolata Forsskal
Sapotaceae Juss.	*Gambeya gorungosana* (Engl.) Liben
	Gambeya cf. *gorungosana* (Engl.) Liben
	Englerophytum rwandense (Troupin) ined.
Sladeniaceae Airy Shaw	*Ficalhoa laurifolia* Hiern.
Icacinaceae Miers	*Apodytes dimidiata* E.Mey. ex Arn.
Apocynaceae Juss.	*Marsdenia angolensis* N.E. Br.
	Secamone racemosa (Benth.) Klack.
	Secamone cf. *racemosa* (Benth.) Klack.
	cf. *Saba comorensis* (Bojer ex A. DC.) Pichon
Gentianaceae Juss.	*Anthocleista grandiflora* Gilg
	cf. *Mondia* aff. *whitei* (Hook. f.) Skeels
	Tacazzea apiculata Oliver
	Pleiocarpa pycnantha (K. Schum.) Stapf
	Tabernaemontana johnstonii Pichon
	Tabernaemontana cf. *johnstonii* Pichon
	Tabernaemontana odoratissima (Stapf) Leeuwenb.
	Tabernaemontana stapfiana Britten
	Landolphia buchananii (Hallier f.) Stapf
Loganiaceae R. Br. ex Mart.	*Strychnos lucens* Baker
Rubiaceae Juss.	*Hymenodictyon floribundum* (Hochst. & Steud.) B.L. Rob.
	Heinsenia diervilleoides K. Schum.
	Keetia gueinzii (Sond.) Bridson
	Rytigynia cf. *bagshawei* var. *lebrunii* (Robyns) Verdc.
	Rytigynia kigeziensis Verdc.
	Coffea eugenioides S. Moore
	Sericanthe leonardii (Halle) Robbrecht
	Tricalysia niamniamensis Schweinf. ex Hiern
	Leptactina platyphylla (Hiern) Wernham
	Pavetta bagshawei S. Moore
	Pavetta rwandensis Bridson

Rubiaceae Juss.	*Rutidea fuscescens* Hiern
	Rutidea orientalis Bridson
	cf. *Rutidea orientalis* Bridson
	Oxyanthus troupinii Bridson
	Oxyanthus cf. t*roupinii* Bridson
	Oxyanthus speciosus DC.
	Oxyanthus cf. *speciosus* DC.
	Sabicea bequaertii De Wild.
	Virectaria major (K. Schum.) Verdc.
	cf. *Virectaria major* (K. Schum.) Verdc.
	Galiniera saxifraga (A.Rich.) Bridson
	Otiophora pauciflora ssp. burttii (Milne.-Redh.) Verdc.
	Chassalia subochreata (DeWild.) Robyns
	Psychotria mahonii C.H. Wright
	Psychotria cf. *mahonii* C.H. Wright
	Psychotria cf. *parvistipulata* E.M.A. Petit
	Psychotria peduncularis (Salisb.) Steyerm.
	Psychotria cf. *peduncularis* (Salisb.) Steyerm.
	Psychotria aff. *peduncularis* (Salisb.) Steyerm.
	Lasianthus kilimandscharicus K. Schum.
	Lasianthus cf. *kilimandscharicus* K. Schum.
	Spermacoce princeae (K. Schum.) Verdc.
	cf. *Spermacoce princeae* (K. Schum.) Verdc.
	Hedythyrsus thamnoideus (K.Schum.) Bremek.
Convolvulaceae Juss.	*Ipomoea involucrata* Beauv.
Solanaceae Juss.	*Solanum chrysotrichum* Schltdl.
	Solanum terminale Forssk.
Acanthaceae Juss.	*Acanthus ueleensis* De Wild.
	Sclerochiton vogelii (Nees) T. Anderson
	Brillantaisia cicatricosa Lindau
	Brillantaisia owariensis P. Beauv.
	Mimulopsis arborescens C.B. Clarke
	Mimulopsis excellens Lindau
	Mimulopsis cf. *excellens* Lindau
	Mimulopsis runssorica Lindau
	Mimulopsis solmsii Schweinf.
	Mimulopsis cf. *solmsii* Schweinf.
	cf. *Mimulopsis solmsii* Schweinf.
	Brachystephanus holstii Lindau
	Isoglossa vulcanicola Mildbr.
	Anisosepalum humbertii (Mildbr.) E. Hossain
	Thunbergia vogeliana Benth.
Bignoniaceae Juss.	*Kigelia africana* (Lam.) Benth. ssp. *africana*
	Markhamia lutea (Benth.) K. Schum.
Lamiaceae Martinov	*Clerodendrum buchananii* (Roxb.) Walp.
	Clerodendrum johnstonii Oliv.
	Clerodendrum cf. *johnstonii* Oliv.
	Rotheca bukobensis (Gürke) Verdc.
	Isodon ramosissimus (Hook. f.) Codd
	Platostoma montanum (Robyns) A.J. Paton
	Coleus maculosus ssp. *edulis* (Vatke) A.J. Paton, comb. nov.
	Coleus cf. *maculosus* ssp. *edulis* (Vatke) A.J. Paton, comb. nov.
	Coleus melleri (Baker) A.J. Paton & Phillipson, comb. nov.
	Coleus cf. *melleri* (Baker) A.J. Paton & Phillipson, comb. nov.
	Coleus sylvestris (Gürke) A.J. Paton & Phillipson
	cf. *Coleus maculosus* ssp. *edulis* (Vatke) A.J. Paton, comb. nov.
	Pycnostachys goetzenii Gürke

Lamiaceae Martinov	*Pycnostachys meyeri* Gürke *Coleaus autranii* Briq. *Coleaus* cf. *autranii* Briq.
Oleaceae Hoffmanns. & Link	*Olea capensis* ssp. *macrocarpa* (C.H. Wright) I. Verd. cf. *Olea capensis* ssp. *macrocarpa* (C.H. Wright) I. Verd.
Plantaginaceae Juss.	*Sibthorpia europaea* L. *Veronica abyssinica* Fres.
Stilbaceae Kunth	*Nuxia congesta* R.Br. ex Fresen.
Aquifoliaceae Bercht & J. Presl	*Ilex mitis* (L.) Radlk.
Asteraceae Bercht. & J. Presl	*Mikaniopsis tedliei* (Oliv. & Hiern) C.D. Adams *Mikaniopsis usambarensis* (Muschl.) Milne-Redh. *Senecio* cf. *nyungwensis* Macquet *Senecio maranguensis* O. Hoffm. *Senecio mariettae* Muschl. cf. *Senecio mariettae* Muschl. *Senecio subsessilis* Oliv. & Hiern. *Senecio* cf. *subsessilis* Oliv. & Hiern. *Crassocephalum ducis-aprutii* (Chiov.) S. Moore *Crassocephalum montuosum* (S.Moore) Milne-Redh. *Crassocephalum rubens* (Jacq.) S. Moore *Crassocephalum vitellinum* (Benth.) S. Moore *Solanecio mannii* (Hook. f.) C. Jeffrey cf. *Solanecio mannii* (Hook. f.) C. Jeffrey *Gynura scandens* O. Hoffm. *Conyza welwitschii* (S.Moore) Wild. *Helichrysum* cf. *foetidum* (L.) Moench *Mikania cordata* (Burm. f.) B.L. Rob. *Mikania chenopodiifolia* Willd *Sonchus* cf. *bipontini* Asch. *Bothriocline* cf. *nyungwensis* Wech. *Bothriocline ruwenzoriensis* (S. Moore) C. Jeffrey *Gymnanthemum auriculiferum* (Hiern) Isawumi *Orbivestus karanguensis* (Oliv.) H. Rob. *Monosis conferta* (Benth.) C. Jeffrey *Baccharoides kirungae* (R.E.Fr.) Isawumi, El-Ghazaly & B. Nord. *Vernonia scaettae* Humbert & Staner
Campanulaceae Juss.	*Canarina eminii* Asch. ex Schweinf. cf. *Lobelia giberroa* Hemsl. *Lobelia petiolata* Hauman
Apiaceae Lindl.	*Sanicula elata* Buch.-Ham. ex D.Don *Afroligustrum runssoricum* (Engl.) P.J.D. Winter cf. *Afroligustrum runssoricum* (Engl.) P.J.D. Winter *Centella asiatica* (L.) Urb.
Araliaceae Juss.	*Astropanax goetzenii* (Harms) Lowry, G.M. Plunket, Gostel & Frodin *Astropanax abyssinicus* (Hochst. ex A. Rich.) Seem. *Astropanax myrianthus* (Baker) Lowry, G.M. Plunkett, Gostel & Frodin *Polyscias fulva* (Hiern) Harms cf. *Polyscias fulva* (Hiern) Harms
Pittosporaceae R. Br.	*Pittosporum mildbraedii* Engl.
Pinaceae Spreng. ex Rudophi	*Pinus* cf. *caribaea* Morelet *Pinus patula* Schltdl. & Cham.

Podocarpaceae ENDL.	*Podocarpus latifolius* BLUME
Cyatheaceae KAULF.	*Alsophila manniana* (HOOK.) R.M. TYRON
Hymenophyllaceae MART.	*Hymenophyllum floribundum* KUNTH
	Hymenophyllum triangulare BAKER
Dennstaedtiaceae LOTSY	*Blotiella bouxiniana* PIC.SERM.
	Blotiella cf. *bouxiniana* PIC.SERM.
	Blotiella glabra (BORY) TRYON
	Blotiella cf. *glabra* (BORY) TRYON
	Blotiella stipitata (ALSTON) FADEN
	Blotiella cf. *stipitata* (ALSTON) FADEN
	Blotiella trichosora PIC. SERM.
	Pteridium aquilinum (L.) KUHN
	Microlepia speluncae (L.) T. MOORE
	cf. *Microlepia speluncae* (L.) T. MOORE
	Hypolepis sparsisora (SCHRAD.) KUHN
	Histiopteris incisa (THUNB.) J.SM.
	cf. *Hypolepis goetzenii* REIMERS
Pteridaceae E.D.M. KIRCHN.	*Antrophyum mannianum* HOOK.
	Antrophyum cf. *mannianum* HOOK.
	Haplopteris guineensis (DESV.) E.H. CRANE
	Vittaria reekmansii PIC.SERM.
	Pteris cf. *auquieri* PIC. SERM.
	Pteris catoptera KUNZE
	Pteris cf. *catoptera* KUNZE
	Pteris cf. *dentata* FORSSK.
	Pteris cf. *microlepis* PIC. SERM.
	Pteris cf. *preussii* HIERON.
	Pteris aff. *preussii* HIERON.
	Pteris cf. *pteridioides* (HOOK.) BALLARD
Aspleniaceae NEWMAN	*Asplenium africanum* DESV.
	Asplenium cf. *anisophyllum* KUNZE
	Asplenium bugoiense HIERON.
	Asplenium cf. *bugoiense* HIERON.
	Asplenium burundense PIC. SERM.
	Asplenium cf. *burundense* PIC. SERM.
	Asplenium cf. *christii* HIERON.
	Asplenium dregeanum KUNZE
	Asplenium cf. *dregeanum* KUNZE
	Asplenium erectum BORY EX WILLD.
	Asplenium cf. *erectum* BORY EX WILLD.
	Asplenium cf. *elliottii* C.H. WRIGHT
	Asplenium aff. *elliottii* C.H. WRIGHT
	Asplenium friesiorum METT.
	Asplenium cf. *friesiorum* METT.
	Asplenium aff. *friesiorum* METT.
	Asplenium gemmascens ALSTON
	Asplenium cf. *gemmiferum* SCHRAD.
	Asplenium aff. *gemmiferum* L.
	Asplenium linckii KUHN
	Asplenium cf. *linckii* KUHN
	Asplenium loxoscaphoides BAKER
	Asplenium cf. l*oxoscaphoides* BAKER
	Asplenium aff. l*oxoscaphoides* L.
	Asplenium mannii HOOK.
	Asplenium cf. *mannii* HOOK.
	Asplenium aff. *megalura* HIERON.
	Asplenium mildbraedii HIERON.

Aspleniaceae Newman	*Asplenium* cf. *mildbraedii* Hieron.
	Asplenium normale D. Don
	Asplenium pellucidum ssp. *pseudohorridum* (Hieron.) Schelpe
	Asplenium protensum Schrad.
	Asplenium cf. *protensum* Schrad.
	Asplenium aff. *protensum* Schrad.
	Asplenium cf. r*eekmansii* Pic. Serm.
	Asplenium rukararense Hieron.
	Asplenium sandersonii Hook.
	Asplenium cf. *sandersonii* Hook.
	Asplenium tenuicaudatum Pic.Serm.
	Asplenium cf. *tenuicaudatum* Pic.Serm.
	Asplenium theciferum (Kunth) Mett.
	Asplenium cf. *theciferum* (Kunth) Mett.
	cf. *Asplenium friesiorum* C.Chr.
	cf. *Asplenium mannii* Hook.
	cf. *Asplenium mildbraedii* Hieron.
Tectariaceae Panigrahi	*Tectaria coadunata* (J. Sm.) C. Chr.
	Tectaria cf. *coadunata* (J. Sm.) C. Chr.
	Tectaria gemmifera (Fée) Alston
Dryopteridaceae Herter	*Didymochlaena truncolata* (Sw.) J. Sm.
	Dryopteris kilemensis (Kuhn) Kuntze
	Dryopteris cf. *kilemensis* (Kuhn) Kuntze
	Dryopteris cf. *pentheri* (Krasser) C. Chr.
	Dryopteris cf. *schimperiana* (Hochst. ex A. Braun) C. Chr.
Lomariopsidaceae Alston	*Elaphoglossum aubertii* (Desv.) T. Moore
	Elaphoglossum cf. *aubertii* (Desv.) T. Moore
	Elaphoglossum acrostichoides (Hook. & Grev.) Schelpe
	Elaphoglossum kivuense Schelpe
	Elaphoglossum cf. k*ivuense* Schelpe
	Elaphoglossum cf. r*wandense* Pic. Serm.
	Elaphoglossum tanganjicense Krajina ex Pic. Serm.
Davalliaceae M.R. Schomb. ex A.B. Frank	*Nephrolepis undulata* (Afzel. ex Sw.) J. Sm.
Polypodiaceae J. Presl. & C. Presl.	*Drynaria volkensii* Hieron.
	Loxogramme abyssinica (Baker) M.G.Price
	Loxogramme cf. *abyssinica* (Baker) M.G.Price
	Loxogramme lanceolata (Sw.) C. Presl
	Pleopeltis macrocarpa (Bory ex. Willd.) Kaulf.
	Grammitis flabelliformis (Poir.) C.V. Morton
Arthropteridaceae H.M. Liu, Hovenkamp & H. Scheid	
	Arthropteris monocarpa (Cordem.) C. Chr.
	Arthropteris cf. *monocarpa* (Cordem.) C. Chr.
Athyriaceae Alston	*Athyrium newtonii* (Baker) Diels
Lycopodiaceae P. Beauv. ex Mirb.	*Lycopodium clavatum* L.
Fissidentaceae Schimp.	*Leucobryum madagassum* Besch.
Bartramiaceae Schwägr.	*Breutelia diffracta* Mitt.
Bryaceae Schwägr.	*Rhodobryum keniae* (Müll. Hal.) Broth.
Rhizogoniaceae Broth.	*Pyrrhobryum spiniforme* (Hedw.) Mitt.

Racopilaceae Kindb.	*Racopilum africanum* Mitt.
Hypnaceae Schimp.	*Hypnum cupressiforme* Hedw.
Meteoriaceae Kindb.	*Pilotrichella ampullacea* (Müll. Hal.) A. Jaeger
Neckeraceae Schimp.	*Porotrichum elongatum* (Welw. & Duby) A. Gepp *Porotrichum variifolioides* (DeSloover) Enroth
Plagiochilaceae Müll.Frib.	*Plagiochila* cf. *heterostipa* Steph. *Plagiochila squamulosa* Mitt. *Plagiochila* cf. *squamulosa* Mitt.
Ramalinaceae C. Agardh	*Ramalina celastri* (Sprengel) Krog & Swinscow
Peltigeraceae Dumort.	*Peltigera dolichorhiza* Nyl.

Also found: ***Piperaceae***: cf. *Piper* sp., 4 species of Peperomia, cf. *Peperomia* sp.; ***Annonaceae***: cf. *Uvaria* sp.; ***Lilianae* sp.;** ***Araceae***: *Araceae* sp., *Culcasia* sp.; ***Asparagaceae***: *Chlorophytum* sp.; ***Commelinaceae***: 3 species of *Commelina*, cf. *Commelina* sp.; ***Cyperaceae***: 6 species of *Cyperaceae*, 10 species of *Cyperus*; ***Poaceae***: 13 species of *Poaceae*, *Sporobolus* sp., *Oplismenus* sp., 2 species of *Panicum*, *Festuca* sp.; ***Zingiberaceae***: *Aframomum* sp.; ***Menispermaceae***: *Stephania* sp., *Tiliacora* sp.; ***Crassulaceae***: *Kalanchoe* sp.; ***Rosanae* sp.**; ***Vitaceae***: 3 species of *Cyphostemma*, *Cissus* sp.; ***Fabaceae***: 4 species of *Fabaceae*; ***Moraceae***: 11 species of *Ficus*; ***Rosaceae***: 10 species of *Rubus*; ***Urticaceae***: 2 species of *Urticaceae*, *Elatostema* sp., 3 species of *Pilea*, 2 cf. *Pilea* sp.; ***Begoniaceae***: cf. *Begonia* sp.; ***Cucurbitaceae***: 22 species of *Cucurbitaceae*, 3 species of *Coccinia*, 3 species of *Cucumis*, 2 species of cf. *Cucumis*, *Momordica* sp., 3 species of *Zehneria*; ***Celastraceae***: 3 species of *Salacia*, cf. *Hippocratea* sp.; ***Achariaceae***: *Lindackeria* sp.; ***Chrysobalanaceae***: *Chrysobalanaceae* sp.; ***Euphorbiaceae***: 2 species of *Euphorbiaceae*, 3 species of *Acalypha*; ***Passifloraceae***: 2 species of *Adenia*; ***Phyllanthaceae***: *Bridelieae*, *Phyllanthus* sp.; ***Putranjivaceae***: *Drypetes* sp.; ***Rhizophoraceae***: *Cassipourea* sp.; ***Melastomataceae***: *Tristemma* sp.; ***Myrtaceae***: cf. *Syzygium* sp.; ***Sapindales*** sp.; ***Meliaceae*** sp.; ***Rutaceae***: *Rutaceae* sp., *Toddalia* sp.; ***Sapindaceae***: *Pancovia* sp.; ***Malvaceae***: *Malvaceae* sp., 2 species of *Microcos*, cf. *Hibiscus* sp., 2 species of *Pavonia*; ***Loranthaceae*** sp.; ***Olacaceae***: *Octoknema* sp.; ***Amaranthaceae***: *Amaranthaceae* sp., 4 species of *Celosia*, 3 species of *Sericostachys*, cf. *Sericostachys* sp., *Pupalia* sp.; ***Caryophllyaceae***: 3 species of *Caryophyllaceae*, cf. *Stellaria* sp., *Drymaria* sp.; ***Polygonaceae***: *Rumex* sp., *Polygonum* sp.; ***Balsaminaceae***: *Impatiens* sp.; ***Primulaceae***: *Primulaceae* sp., *Embelia* sp.; ***Sapotaceae***: *Chrysophyllum* sp.; ***Apocynaceae***: 10 species of *Apocynaceae*, cf. *Alafia* sp., *Pentatropis* sp., cf. *Marsdenia* sp., cf. *Ancylobothrys* sp.; ***Gentianaceae***: *Tabernaemontana* sp., cf. *Tabernaemontana* sp.; ***Loganiaceae***: *Strychnos* sp.; ***Rubiaceae***: 23 species of *Rubiaceae* sp., cf. *Rubiaceae* sp., *Canthium* sp., cf. *Canthium* sp., 4 species of *Keetia*, 9 species of *Rytigynia*, cf. *Rytigynia* sp., *Vangueria* sp., *Tricalysia* sp., *Mussaenda* sp., *Pavetta* sp., cf. *Oxyanthus* sp., cf. *Galiniera* sp., 5 species of *Psychotria*, cf. *Lasianthus* sp.; ***Ehretiaceae***: *Ehretia* sp.; ***Convolvulaceae***: *Cuscuta* sp., 2 species of *Ipomoea*; ***Solanaceae***: *Solanum* sp.; ***Acanthaceae***: 14 species of *Acanthaceae*; *Acanthopale* sp., 2 species of *Mimulopsis*, *Brachystephanus* sp., *Isoglossa* sp., cf. *Isoglossa* sp. I, cf. *Justicia* sp. I, 2 species of *Thunbergia*; ***Lamiaceae***: *Lamiaceae* sp., 3 species of *Clerodendrum*, *Leucas* sp., 2 species of *Plectranthus (Coleus)*; ***Oleaceae***: *Jasminum* sp.; ***Asteraceae***: 10 species of *Asteraceae*, cf. *Asteraceae* sp., cf. *Microglossa* sp., *Anisopappus* sp., 4 species of *Mikaniopsis*, 6 species of *Senecio*, 2 species of *Crassocephalum*, 2 species of *Gynura*, cf. *Gynura* sp., *Conyza* sp. I, 3 species of *Helichrysum*, cf. *Helichrysum* sp. III, 7 species of *Mikania*, *Lactuca* sp., *Vernonieae* sp., 8 species of *Vernonia*, 2 species of cf. *Vernonia*; ***Apiaceae***: *Afroligustrum* sp.; ***Araliaceae***: *Hydrocotyle* sp.; 194 **Gen. indet. spec. indet.**; ***Hymenophyllaceae***: 2 species of *Trichomanes*, 26 species of *Polypodiales*; ***Dennstaedtiaceae***: 6 species of *Blotiella*; ***Pteridaceae***: *Vittaria* sp., 9 species of *Pteris* sp.; ***Aspleniaceae***: 42 species of *Asplenium*; ***Tectariaceae***: 6 species of *Tectaria*; ***Thelypteridaceae***: *Thelypteridaceae* sp., *Ampelopteris* sp., *Christella* sp.; ***Dryopteridaceae***: 20 species of *Dryopteris*; ***Lomariopsidaceae***: *Elaphoglossum*; ***Athyriaceae***: *Athyrium* sp.; ***Woodsiaceae***: 8 species of *Woodsiaceae*, 8 species of *Diplazium*, cf. *Diplazium* sp.; ***Marattiaceae***: *Marattia* sp.; ***Selaginaceae***: *Selaginella* sp.; ***Bryopsida***: 12 species of *Bryopsida*; ***Calymperaceae***: *Syrrhopodon* sp.; ***Dicranaceae***: *Atractylocarpus* sp., *Campylopus* sp.; ***Fissidentaceae***: 2 species of *Fissidens*; ***Trachypodaceae***: *Trachypodopsis* sp.; ***Pilotrichaceae***: *Cyclodictyon* sp.; ***Lepidoziaceae***: cf. *Teleranea* sp.; ***Lichen***: 2 species of *Lichen*

Erklärung

Hiermit erkläre ich, dass ich die eingereichte Dissertation selbstständig verfasst habe und alle von mir für die Arbeit benutzten Hilfsmittel und Quellen in der Arbeit angegeben sowie die Anteile etwaig beteiligter Mitarbeiterinnen oder Mitarbeiter sowie anderer Autorinnen oder Autoren klar gekennzeichnet habe. Eine entgeltliche Hilfe von Vermittlungs- oder Beratungsdiensten (Promotionsberater oder andere Personen) wurde dabei von mir nicht in Anspruch genommen. Zudem wurde die Dissertation von mir nicht in gleicher oder ähnlicher Form als Prüfungsarbeit für eine staatliche oder andere wissenschaftliche Prüfung im In- oder Ausland eingereicht. Ebenfalls wurde von mir keine gleiche oder eine andere Abhandlung in einem anderen Fachbereich oder einer anderen wissenschaftlichen Hochschule als Dissertation eingereicht. Mir ist bewusst, dass ein Verstoß gegen einen der vorgenannten Punkte den Entzug des Doktortitels bedeuten und ggf. auch weitere rechtliche Konsequenzen haben kann.

Koblenz, den: 07.07.2021