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Influence of anthropogenic disturbance on the diversity of flora and vegetation of Cyamudongo rainforest, the adjacent forestry plots and the Western Nyungwe main forest block

von

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DEDICATION

This work is dedicated

To my late parents Nyiranziza Perpetue and Bushishi Arstide

My late father in law Bushishi David and my mother in law Mukamabano Marine

My wife Nyirakamana Pélagie

My sons

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SUMMARY

Human population pressure increased with the population growth around the NNP and Cyamudongo with disturbance impacts on the forests isolating populations into fragments and today, Cyamudongo natural forest is located a way at a distance of at least 8.5 km horizontal distance to Nyungwe main block with a surface area estimated at 300 ha. Under Cyamudongo project implementation, there was a need to understand how the flora diversity responded to human imposed challenges and to forest restoration initiatives. Three physiognomic landscapes forest were identified and considered for three phases of vegetation survey in Cyamudongo and related to the closest area of Nyungwe main block. In this study, 15 transects were laid in each physiognomic forest landscape and 10 and 5 plots were set respectively in Cyamudongo and Gasumo study area. In total, 315 phytosociological relevés were performed and the Braun-Blanquet methods used for three times vegetation surveys. Species life-forms and chorophyte were evaluated and tree species dbh and height have been measured. Data were subjected to different statistical analyses using different softwares such as PAST, R 3.5.2, and SPSS. The mapping was done using Arc GIS and the Multi-Spectral Remote Sensing used to find NDVI for the vegetation classification.

NDVI trends showed that there has been fluctuations in vegetation classifications of the studied area. In this study, 494 vascular plant species from 106 families were harbored in the study area and distributed differently among forest landscapes and study phases. Although, 43.54% were common to Cyamudongo and Gasumo landscapes while 48.54 % of species diversity were hold only by Cyamudongo and 7.92% confined to Gasumo and 12 in total were found new records for Rwanda while several others suspected require detailed research for identification showing how the flora diversity of Cyamudongo is of special interest and extremely important for discoveries.

The finding of the study on diversity indices, the PCA, CA and the Cluster analysis, all statistical analyses (MANOVA, ANOVA) and life form spectra unanimously showed that the anthropogenic disturbance shaped the vegetation cover, the floristic composition, the species diversity, the forest landscapes community structure, the life form spectrum and the phytoclimate of Cyamudongo and Gasumo forest landscapes. Although, the vegetation analysis couldn't clearly identify communities and sub-communities at the initial and final vegetation surveys and cluster groups were heterogeneous as well as overlapping and species associations not clearly defined due to the high level of similarities in species composition among forest landscapes and vegetation surveys. The species diversity was found high in secondary forest and Gasumo landscape forest and low in the primary forest and the buffer zone of Cyamudongo and the disturbance with gaps openings was found to be associated to the species diversity with a seasonal variation. The patterns of dbh for the buffer zone and of the size classes of all landscapes with an inverted 'J' indicated a healthy regeneration in the forest landscapes and tree species explained a good regeneration and recruitment capacity. Different shapes in the pattern of dbh with respectively an inverted ‘J’, ‘J ‘and ‘U’ for the buffer zone, primary and together the secondary and Gasumo forest landscapes indicated differences in the landscapes health and degree of regeneration and recruitment capacity.

Findings from differents measuements showed at which extend human activities have shaped the flora diversity and structure of forest landcapes studied. For instance, disturbances due human activities were daily oberved and trees were logged by neighboring communities such as Batwa populations at Cyamudongo and local populations at Gasumo. Some species were evenly observed targeted for their barks such as *Ocotea usambarensis, Parinari excelsa* for medicines and many others for their wood quality, fire wood collection and for agricultural purposes.

In the period of Cyamudongo project implementation, important achievements included the increase of forest biomass and therefore the photosynthetic capacity and the evapotranspiration potential that influence the rainfall regime; the regulation of weather conditions and then species diversity; supporting local communities and limiting human activities; raising awareness on conservation and protection of biodiversity and improving of living conditions of neighboring populations by providing paid employment and so to restore to the Cyamudongo forest ecosystem functions. Moreover, Cyamudongo forest remains vulnerable as surrounded by local communities with a high population pressure relying on forest resources for its survival. Cyamudongo harbors a high level of endemism and is a small hotspot for biodiversity conservation. It is therefore recommended to strengthen conservation and protection measures and continue the support of local communities.

CHAPTER 1. GENERAL INTRODUCTION

1.1 Background of the study

A forest ecosystem is characterized by the composition, function and the structure of itself. The forest composition is described by proportions of various species that explain a major aspect of biodiversity. The function involves all the roles and processes that are played by an ecosystem such as productivity, nutrients conservation, and regulation of water cycles and the structure concerns different features such as trees, snags, logs of various sizes and conditions, their special distribution, such as whether they are uniformly spaced or clustered (Franklin *et al.*, 2002).

The forest is most important on Earth and harbors the planet's most interesting ecosystems with 90% of terrestrial biodiversity among which a variety of birds, animals, and plants (Brooks *et al.*, 2006, Joseph, 2010). Forests remain the source of more than 5,000 products. These range from the aromatic oil, herbal drugs, fuel, furniture, food and clothes. They are solution to soil erosion, regulate the climate and purify water. The benefits of forest are far extended to the inspiration of human lives with art, research, religion. Furthermore, forests have been found to be essential for the survival and the well-being to all the 7 billion people living on the Earth (Joseph, 1999) as they globally regulate the carbon flux by its sequestration and storage in forest biomass (Gullison *et al.*, 2007) and they are particularly important in terms of species richness and their concentration of endemic species (Brooks *et al.*, 2006).

Tropical forests represent more than a half of the total forests in the world (Babin, 2004) and are located between the two tropics, more less in the latitudes 23° N and 23° S (Oldeman, 1989). In this area, during the seasonal progression, the sun stays directly overhead at some points and the flux of solar energy remains high, because of sunlight projected at 90^0 angle to the earth surface. As a consequence, it results in a high rate of water evaporation and evapotranspiration respectively over the tropical oceans and the tropical land surfaces (Oldeman, 1989) leading to an increase of temperature and moist air at tropical latitudes. Due to the gradient in air pressure, the air rises and cools resulting in a condensation of water from the air mass and subsequent rainfall.

A wind circulation pattern known as Hadley cells results from the air mass which becomes dry and directed polewards from the tropics. The dry air mass descends at subtropical latitudes near $23–30^0$ N and S and creates a region of high pressure corresponding the deserts world distribution. These climate circulation patterns lead to the warm and wet in the equatorial zone which corresponds to a large band of tropical forests along the equator (**Figure 1**). Tropical forest are habitat of a half of the world's animal and plant diversity on the surface area of only one tenth of the total world's area (Nageswara-rao *et al.*, 2011).

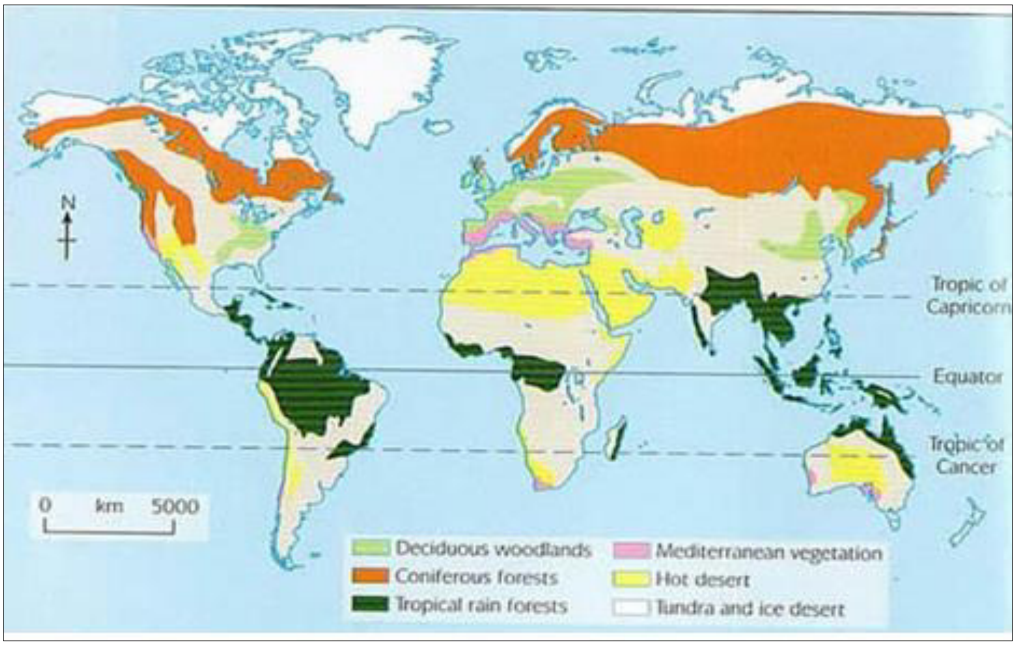

Figure 1: Global distribution of tropical forests (Thomas & Baltzer, 2002)

Differences in the distribution of rainfall throughout the year, the elevation and the soil type are distinguishing the main types of tropical forests. Tropical forests that experience ever-wet conditions, with more than 100 mm of precipitations in every month of the year are referred to tropical rainforests (Thomas & Baltzer, 2002).

Tropical forests that experience ever-wet conditions with no month receiving less than 100 mm of precipitations are generally referred to tropical rainforests. However, a tropical "moist forest" that is receiving annual rainfall exceeding 4000mm is, in strict sense sometimes different from a tropical 'rainforests' (Oldeman, 1989).

The earth's function at local, regional and global scales has been under the dependence of the tropical forest's roles and rich biodiversity (Malhi *et al.*, 2013) and the recent decades was marked by an increasing curiosity of scientists and tourists impressed by the large extend of sophisticated fauna and flora diversity interacting with various ecological conditions (Nageswara-rao *et al.*, 2011) and responding to human basic needs (Tilman, 2000).

Human dependence on basic needs in terms of food, medicines, shelter, fuel, settlement, and infrastructure became severely threatening in the last decades. It resulted in a continuous decrease of the species richness and diversity as forest resource have been constantly harvested and eroded; large areas of forests fragmented, cleared, and transformed in agricultural lands and grazing areas (Nageswara-rao *et al*., 2011).

The importance of rainforests is undeniable. After an overview of functions of the rainforests Park (1993) considered rainforests as the most abundant source of life that nothing else can replace. The same functions were also highlighted by several authors. These include all ecosystems services such as environment and climate regulation (Park (1993); human life support, biodiversity support, cultural benefits (Dao *et al*., 2016; Naeem *et al*., 2002; Angelsen & Kaimowitz, 1999; Gradstein *et al*., 2008) while Malhi *et al.* (2013) qualified the African rainforests qualified as the "green heart of Africa".

In tropical forests, mountain forests harbor high species richness and a source of water for millions of people inhabiting the tropics and were in fact accounted for hotspots for biodiversity. The 25 worldwide hotspots, are mostly found in tropical forests with a high level of endemism and under a high population pressure and include the Albertine rift of Africa (Cincotta *et al*., 2000).

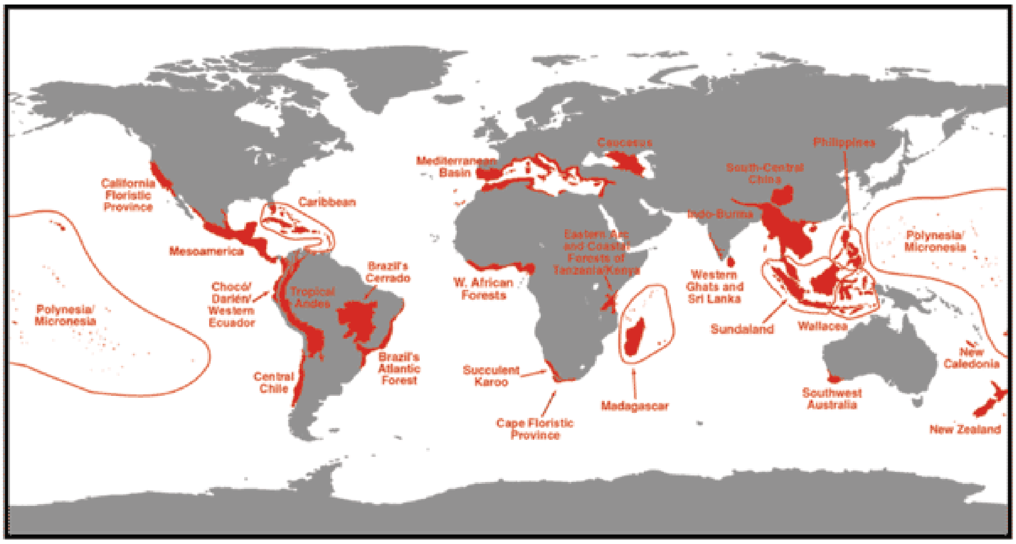

Figure 2: The distribution of the 25 biodiversity hotspots (Myers et al., 2000)

The tropical forests face multiple threats (Nageswara-Rao *et al*., 2012). They are environments among the most important locations of global land use and cover change (Chowdhury, 2006). Different major rainforest regions are defined by their geographical location, ecological conditions, the composition and structure of the rainforest, the level of human pressure to each entity and how the different biological unities in rainforests respond to human threats to each of the rainforest (Corlett *et al*., 2008).

The causes of tropical deforestation have been classified into proximate causes and underlying forces. At the proximate level, tropical deforestation was best explained by multiple factors. The dominating factors are agricultural expansion, wood extraction, and infrastructure expansion, which varied clearly on regional scale. At the underlying level, tropical deforestation was also explained by multiple factors but they rather acting synergistically than single-handedly, with more than one third of the cases being driven by the full interplay of economic, institutional, technological, cultural, and demographic variables (Geist & Lambin, 2006).

Past decades have been marked by changes in factors of tropical forest destruction and important threats which will keep changing for the future. The growth of industries and the need of improved wealth in developing countries are predominant factors and biofuels and climate change are also potential factors of changes in tropics. These changes are predicting a future destruction of forests with genetic depletion due to emerging pathogens (William, 2015).

Chakravarty *et al.* (2012) have identified several agents of deforestation as slash and burn farmers, commercial farmers, ranchers, loggers, firewood collectors, infrastructure developers and any other who are cutting down the forests and defined the causes of deforestation like forces that stimulate the agents to clear the forests for different anthropogenic activities including economic growth, overpopulation and poverty, air pollution, war and military role among others.

The clearing of forests and consequences affect in return the economic activity and threaten the livelihoods and cultural integrity of forest-dependent people as argued Angelsen & Kaimowitz (1999). Scheidegger *et al.*(2002) has also observed that human impact on forest has changed species composition as well as species richness and suggested that this impact will undoubtedly continue in the future as long as humans operate in forests. Results from a study by Huang *et al.*(2003), suggested a significant less variations in species richness and stems density in undisturbed natural forest than in disturbed forest.

There is a lot of research activity in the African rainforest zone. The African humid forests have been explored from a variety of perspectives, including archaeology, paleoecology, ecology, climate science, satellite remote sensing, global climate-vegetation modeling, international policy and social science (Malhi *et al.*, 2013). Hilbert (2006) postulated that Biologists and Historians were fascinated by the species richness in tropical forests around 1900s and that more than a hundred years later we remain fascinated, yet not sufficiently close to understanding the origins and long-term maintenance of high species diversity in the tropical forest.

Results of the Global Forest Resources Assessment of the Food and Agriculture Organization of the United Nations (FAO) indicate that between 1990 and 2015, the total forest area declined by 3%, from 4128 Mha to 3999 Mha, and the annual rate of net forest loss halved from 7.3 Mha y^{-1} in the 1990s to 3.3 Mha y^{-1} between 2010 and 2015. Loss of forest area occurred largely in the tropics, from 1966 Mha in 1990 to 1770 Mha in 2015 (Keenan *et al.*, 2015). Archaeological evidence in combination with pollen samples from Burundi, Rwanda, and western Uganda suggests that widespread clearance of forest by humans began in these regions 2,300 years BP (Jolly *et al.*, 2003). Human actions resulted in loss of species through extinctions which has been estimated to be the most alarming issue for conservation practitioners and weeks after weeks, predictions about extinction rates are appearing on headlines in the international press (Willis *et al.*, 2019).

Long-term ecological records in biodiversity conservation suggest their use to greatly enhance many aspects of conservation practice and policy. Specific applications are related to species extinction and particular methods to prioritize those on the IUCN Red list, climate change conservation strategies and the use of the fossil records to determine the errors inherent in species envelope, the responses of communities to environmental changes, the maintenance and restoration of biodiversity hotspots as well as biological invasions (Willis *et al.*, 2019).

In recent years, observers have voiced over the destruction of tropical rainforests in Africa, Asia and Latin America according to Myers & Shane in Rudel (1989) because, the destruction would result in massive species extinctions with depletion of the world’s genetic resources and climatic changes and greenhouse effect.

Africa harbors the world’s second largest tropical forest region with the tropical forests of Central and West Africa, known as the Guineo-Congolian region accounting for 95% of African rainforests including the submontane forest patches of East Africa and the unique forests of Madagascar (Malhi *et al.*, 2013).

Rwanda is a small, mountainous, landlocked country (26338km^2) located in the equatorial highlands of the Albertine Rift Valley. It is bordered by the Democratic Republic of Congo (DRC) to the west, Burundi to the south, Uganda to the north and Tanzania to the east. The western part of the country is dominated by the Congo-Nile divide, and a chain of highlands, running north-south and separating the Congo from the Nile basin. Five Pleistocene volcanic peaks dominate the Congo-Nile highlands in the north (Ntaganda, 2003). Montane forests, Nyungwe forest, Mukura and Gishwati remnant forests as well as the Volcanoes National Park cover the highlands of a surface of almost 1,030 km^2 and are important habitats for biodiversity and ecosystemes services (Adekunle, 2010; Rukundo *et al.*, 2018).

Nyungwe forest National Park has been described as the most biologically important rainforests in central Africa (Fischer & Killmann, 2008). The population density of Rwanda in 2012 was 415 inhabitants per square kilometer and it was found to be the most densely populated country of the continental sub-Saharan Africa and facing with severe resources imbalances (May, 1995). The population has slightly increased in the period 1930 to 1950 followed by a dramatic increase between 1950 and 1970. Thereafter this trend was slightly slowed down until 1990. The population density was only 183 persons per sq. km in 1978 and reached 321 in 2002. Since the census in 2002, the population continued to increase and reached 11millions in the year 2010 (Habiyaremye *et al.*, 2011) and has increased by 2.4 million, which represents an average annual growth rate of 2.6% (National Institute of Statistics of Rwanda, 2012). This population growth in Rwanda has affected the natural rainforests with a continuous and severe loss of biodiversity which has led to the creation of protected areas (Masozera *et al.*, 2006).

The Nyungwe Forest Reserve in southwestern Rwanda (2°15' – 2°55' S, 29°00'– 29°30' E) represents a key area for rainforest conservation. According to Masozera *et al.* (2006), Nyungwe Forest was thought to cover 970 km^2 of mountainous terrain and the be largest tract of forest remaining in the Albertine rift Highlands of East-central Africa. Many species found at Nyungwe occur only in the Albertine Rift region of central Africa, highlighting the considerable importance for conservation of this forest (Plumptre *et al*., 2007). As asserted by Vedder (2000), Nyungwe forest together with the contiguous forest of Kibira National Park in Burundi, forms one of the largest blocks of lower montane forest in Africa which includes vast stretches of forest ranging from 1,600 to 2,950 m and consisting of dynamic mosaic of closed forest, secondary forest, drier forest ridge, swamp forest, large homogenous stands of bamboo and openings with herbaceous plants (Bahigki & Vedder, 1987). This block harbors the Congo-Nile Divide where species of different geographical origin may meet and due to its extension across a wide range of altitudinal zones, it offers a high diversity of habitat (Boxnick *et al*., 2015) with a high level of biodiversity.

Nyungwe is home to 13 primate species, approximately 280 birds species, up to 230 tree species and many Albertine Rift endemics (Plumptre *et al*., 2007).

The climate of Nyungwe is typical of a tropical montane forest and is characterized by very small thermal seasonality and a long wet season from September to May and much drier conditions during the mid-year months. The rainfall average ranges between 1500 and 2500 mm per year. The maximum and the minimum average temperature are found to be 19.6^0 C and 10.9^0 C respectively (Seimon, 2012).

The fragmentation of Nyungwe forest happened long time ago due to the accelerated and extensive land-use change which resulted into two separate rainforests patches. Today, these patches are known as Cyamudongo forest and Nyungwe main block. Originally, the northeastern side of Cyamudongo forest was connected with the Nyungwe main block (Nyirarwasa *et al.*, 2020). Nowadays, it is a small relict forest, located far in the southwest of the country, close to the Nyakabuye town and the border with the Democratic Republic of Congo (DRC), almost 10 km away from Nyunwe main block according to Moore *et al.*(2018). However, the increasing human population pressure with over exploitation for timber, charcoal, fuel wood, farming and medicinal plants extraction for its economic values for survival of local community converted this forest into farmlands and tea plantations (Arakwiye *et al.* 2021). Cyamudongo forest was progressively reduced in size up to 410 ha today which was previously estimated to be 300 ha (Kanyamibwa, 2001).

The figure below shows Cyamudongo forest disconnected from Nyungwe National Park.

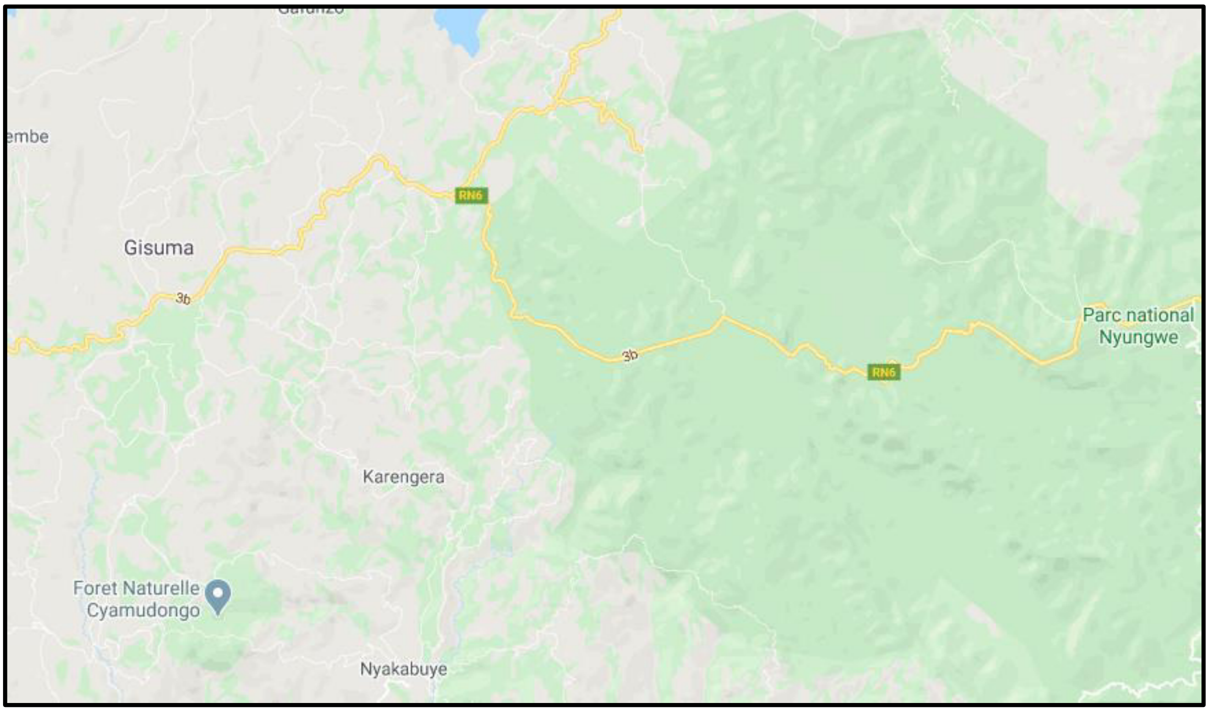

Figure 3: Cyamudongo and Nyungwe rainforests from

https://www.google.com/maps/@-2.502453,29.0191058,12z

The map above shows that the remnant forest patch encompasses the area between three administrative sectors such as Nkungu, Gitambi and Nyakabuye.

Cyamudongo forest (02°33.12'S 28°59.49'E) is a small dense forest patch at 8.5 km horizontal distance to Nyungwe National Park (NNP) which ranges from 1,700 to 2,000 m above sea level and harbors a wide range of flora and fauna species with denser vegetation with fewer clearings than Nyungwe forest (Kanyamibwa, 2001).

1.2 Problem statement

Several studies have been carried out throughout the world's rainforests. Some approaches used intervene as a tool to answer to relevant questions on Cyamudongo spatially disconnected from Nyungwe. It assumed that disturbances modify the physical environment, the spatial and temporal distribution of available resources. Hence, they have influence on the abundance and distribution of populations (Bazzaz, 1983;Tilman, 1982). In the same context, it's argued that fragmented forests are characterized by lower arboreal and shrub density and canopy height, but greater shrub cover (José Luis & Antonio, 2014). Habitat fragmentation is also associated with drastic changes in the floristic composition and structure of vegetation (Harper *et al*., 2005).

The size distribution of trees in a tropical forest conveys much information about site-to-site differences in growth, mortality rates, stem density, canopy architecture and forest structure. An ability to track these structural properties over time enables assessments of directional changes in forest dynamics (Chambers *et al*., 2007). The presence or the absence of species in a region are not only determined by climate and edaphic or site conditions but also by disturbances (Heydari & Mahdavi, 2009).

Several indexes were used to estimate the biological diversity and the species richness. These are like Shannon and Margalef richness indexes found to be good indicators of the health of an ecosystem are used by Mehrvarz *et al.*(2016) and Simpson's Indices, Coleman Rarefaction curves, and „Chao 2" non-parametric species richness estimator curves were used to compare the species richness in a vegetation assemblages (Jones, 2011).

Jouri *et al*. (2011) stated that diversity and richness of plants are reduced by abiotic (slope, feature, altitude, latitude, soil properties, etc.) and biotic (animal and human) factors along time and animal grazing and especially overgrazing, can change plant composition.

Replan & Malaki (2017) have estimated that the geographical distribution of plant species is useful for assessing biodiversity values of regions, countries, and islands where species confined to a particular site. Plants with a narrow distribution are more vulnerable to disturbance and should be taken into account for particular conservation management strategies.

Bermingham *et al.* (2005) also argued that diversity differences among communities occupying similar habitats in different regions (so-called anomalies) provide a strong indication that the history has a lasting effect on the species richness of local communities. The differences among species that co-occur in an ecological community are the result of modifications to a common ancestor that the species all ultimately share. Today, the molecular and analytical methods provide an invaluable new dimension of information to ecologists to evaluate differences among species and to elucidate phylogenetical relationships easier and more reliable (Webb *et al.*, 2002).

The role of dominant species is less important than the species diversity for the stability of plant communities. An increased diversity caused by the removal of a dominant species lead to an increased stability of the community with a prevailing diversity effect, by reducing the competition for limiting resources and modifying the dominance hierarchy in the community (Sasaki & Lauenroth, 2011). The same authors investigated further, the effect of removing dominant species by using various measures of species diversity, functional diversity, and relative abundance of dominant, subdominant and rare species.

Mo *et al.* (2013) have assessed the impacts of human disturbance on species community assembly along with a successional gradient in a traditional managed forest landscape by using the phylogenetic community structure analysis. Theses authors hypothesized that if the environment is the driver of community assembly, the species will be filtered for species traits that enhance the survival, growth and reproduction in specific habitats leading to co-occurrence of closed related species with similar traits (phylogenetic clustering). However, if species interaction drives the community assembly, the species with similar traits will out-compete each other leading to phylogenetically random or dispersed species community (Mo *et al.*, 2013). Plant life forms have been proposed in several studies to explain the relation between a plant and its environment and analyze changes in plant communities. They help to describe the structure of tropical forests and to assess the impact of human activities on tropical landscapes (Ewel & Bigelow, 1996; Gillison, 2006).

The Raunkiaer life forms defined in period between 1905-1913 (Einar Du Rietz, 1931) and reviewed in 1934 and based of the plant's unchanging attributes related to the position of their perennating bud were proposed to explain the relationship between the climate and vegetation where statistical methods applied on them were developed by Smith (1912). The approach has been also used to understand the life history of plant communities (Gibson, 2002). The global spectrum of plant forms provide a foundation to achieve a better understanding of the evolutionary trajectory of vascular plants (Díaz *et al*., 2016). Changes in plant communities have also been investigated by the vegetation cover. Vegetation cover has been used as indicator of human activities in an surveyed area in China (Li *et al*., 2015). The Braun-Blanquet scale was earlier found to be adaptable to assessment of the impact of disturbance by comparing plant coverage values in disturbed areas with those in undisturbed areas having similar species composition (Douglas, 1978).

Estimates of the tropical forest cover inform about changes in forest extent but do not consider the biological diversity within the forest (Morris, 2010). The quantitative estimate of the biological variability is performed using the diversity index to compare biological entities composed of discrete components in space and time (Help *et al*., 1998) where the α diversity is an important measure of the species richness in number of surveyed plots (Zhang *et a*l., 2014). The β diversity measure the degree to which species composition differs and allowed to conclude that that in the emerging human modified landscapes, levels of floristic homogenization will increase at the local scale, resulting in a declined β-diversity as Escobar *et al*. (2013) suggested.

Others important measures such as the Diameter at breast height (Dbh) and the tree height were used to describe forest stands in natural tropical forest and a relationship model has been developed (Mugasha & Eid, 2013).

In Rwanda little is known. The scientific exploration started with the German expedition to Central Africa in the year 1907/1908 (Fischer & Killmann, 2008). Rwanda was almost unknown concerning its flora and fauna (Killmann & Fischer, 2005). The knowledge about plants and plant communities has been gained by the hard work of generations of committed Botanists. Among recognized researchers, Robyns & Troupin produced the Flora of Spermatophytes around 1950 and 1970s-1980s respectively. Fischer & Killman (2008) illustrated the field guide of the Plants of Nyungwe National Park while Fischer *et al* (2010) produced the Orchids of Rwanda.

Based on their publications, the research on the evolution and development of the biodiversity in respect to abiotic and biotic factors is possible. The diversity of the flora and the fauna has been the center of many years of intense researches and several species have been discovered in Nyungwe and in Cyamudongo forest. In discoveries, epiphytes such as orchids and ferns were found more diverse due to the fact that these rainforests constitute their preferred habitat favored by an abundant forest cover as claimed by Krömer & Gradstein (2016) that the abundance of vascular epiphytes is one of the most striking characteristics of tropical rainforests and montane humid forests.

Nyungwe forms a part of the isolated mountain ranges of Africa. Their flora consists of more than 80% of plants which are not known elsewhere, so called endemic species. Nyungwe is part of a floral region called the Afromontane and afroalpine Centre of endemism according to White (1983) in Fischer & Killman (2008). It is known as one of the most beautiful and most species-rich montane rainforests of Africa and the rapid population growth of local communities living around was found correlated with forest losses due to agriculture expansion, timber and non-timber collection, mining activities, charcoal production which resulted in forest fragmentation and reduction of species diversity (Kayiranga *et al*., 2016). Efforts to understand subsequent changes were directed to biodiversity in general (Jolly *et al*., 2003; Plumptre *et al*., 2007; Plumptre *et al*., 2002; Boxnick *et al*., 2015); birds (Kanyamibwa, 2001); primates (Mvunabandi *et al*., 2015a; Chitayat, 2015; Krajewski, 2007; Moore *et al*., 2018), oriented to land cover change (Mlotha, 2018; Kayiranga *et al*., 2016); addressed aspects related to conservation, tourism and policies (Plumptre *et al*., 2017; Plumptre, 2004; Gapusi, 2007; Munanura *et al*., 2017; Kanyamibwa, 2013; Gross-camp *et al*., 2015; Masozera *et al*., 2006 & Rutagarama & Martin, 2006). But no similar study has been undertaken to investigate and understand the flora diversity and the role of human in shaping the structure and composition of forest communities in Cyamudongo and yet there is a lack of data to guide the political decisions and conservation policies and strategies.

The past use and current anthropogenic activities on Cyamudongo and Nyungwe should have modified the forest structure and composition lead the loss of forest functions. This study focuses on Nyungwe and Cyamudongo rainforests because human activities have created a geographical isolation between the two components of Nyungwe National Park that may have caused a modification of distribution patterns of the flora diversity. The goal of this study is to investigate and assess the influence of anthropogenic disturbance on the diversity of the flora and vegetation of Cyamudongo rainforest, its adjacent forestry plots and the Western Nyungwe main forest block.

1.3 Objectives of the study

The present study aimed to understand the structure, the function and the composition of the species diversity and analyze the patterns of floristic homogenization or differentiation between Nyungwe western block and Cyamudongo forest. As Gardner *et al.* (2009) asserted, several threatening factors can alter the composition and structure of remaining assemblage where the configuration of the two habitats on the spatial dissimilarities in species composition (β-diversity) remains poorly understood. The understanding and the knowledge acquired from this study is a provision of tools for Cyamudongo forest and species conservation management strategies as well guiding the Rwandan policy makers.

More specifically, the following objectives were the basis of this study:

1. To establish the taxonomic list of vascular plants in Cyamudongo rainforest, forestry plots and the western Nyungwe main forest block.
2. To measure species richness and the species diversity (Alpha diversity and Beta diversity).
3. To plot the distribution of key species
4. To assess the relationship between the species richness of vascular plants and the intensity of anthropogenic disturbances.
5. To detect plant associations and identify indicator species.
6. To relate the identified plant associations with those described for similar forest types
7. To measure the similarity among Cyamudongo rainforest, the buffer zone plots and the western Nyungwe main forest block;
8. To describe the forest structure based on DBH, tree height, life forms and canopy cover.
9. To establish the relationship between disturbance, vegetation structure and composition
10. To establish the conservation status of key species in Cyamudongo and Nyungwe western block.

1.4 Research hypotheses

The achievement of such objectives will allow testing the following research hypotheses:

1. The plant associations in the western Nyungwe main forest block are similar to those previously described for similar rainforests and differences with Cyamudongo forest are due to anthropogenic activities.
2. The species diversity and abondance is higher in Cyamudongo than in Nyungwe main block and some species are restricted to Cyamudongo.
3. Cyamudongo and its buffer zones are more diverse in vascular plant species than Western Nyungwe main forest block.
4. The disturbance of Cyamudongo has affected plant community composition and key species have been affected.
5. The western Nyungwe main forest block exhibit a higher richness in endemic/rare vascular plant species than Cyamudongo and its adjacent forestry plots.
6. The level of anthropogenic disturbance is a factor of flora diversification in Cyamudongo.
7. Diversity differences among communities occupying similar habitats in different regions provide a strong indication of human impacts on species richness of local plant communities.
8. The size (Dbh and height) distribution of trees in Nyungwe and Cyamudongo forest conveys much information about site-to-site differences in growth, mortality rates, stem density, canopy architecture and forest structure taking place due to anthropogenic disturbances.
9. The number of woody species tends to decrease with increasing diameter at breast height.
10. Within the buffer zone and the secondary forests sites, the human impact is higher than within the primary forest sites and it is reflected by the vegetation structure and composition.

1.5 Study approaches

In this study, a stratified sampling strategy, taking into account physiognomic differences among plant communities was used to establish fifteen transects each in primary forest, secondary forest and the buffer zones. The existing trails in the forest were selected as a baseline for the installation of perpendicular transects in different forest types in the direction of the slope. Each transect was 50m long and enclosed 200m^2 surface area. Forty-five transects were established in Cyamudongo and fifteen transects in western Nyungwe main block respectively. In addition, fifteen and five permanent plots of 10 mx 10 m were respectively were set up in Cyamudongo and in the western Nyungwe main block respectively. A survey of plant diversity was carried out using Braun-Blanquet scale for cover and abundance estimations as described in Poore (2019). The Raunkiaer's life-forms (Smith, 1913) were used to characterize each vascular plant species. The DBH was measured and the height of trees and vegetation cover were estimated within the surveyed plots, whereas individual tree species were counted and the level of disturbance scored.

1.6 Thesis chapters

This works is subdivided into six chapters. The first chapter introduces the topic and draws a background on rainforests and human action. It states the problem, objectives as well as hypotheses of the thesis and the study approaches. The second chapter is a literature review which identifies research already completed on rainforest especially on Nyungwe National Park and how the anthropogenic disturbances have shaped the vegetation and its diversity. The third chapter presents materials and methods used to collect and analyze data. The fourth chapter contains the research results while chapter five discuss results with findings of other researchers and evaluates if they fulfill expectations and hypotheses of the research. The sixth chapter draws out the findings and conclusion regarding the research problem, sub-problems or hypotheses, it is an outlook as guidance for nature conservation, suggestions for ongoing research and possible questions or information which are generated to improve the knowledge and nature conservation practices.

CHAPTER 2. LITERATURE REVIEW

This review summarizes the existing literature on the history of tropical rainforest, biodiversity surveys within sites in tropical forests and Albertine Rift. More specifically were explored the biodiversity of Nyungwe National Park and the impact of anthropogenic disturbance on the flora diversity. It is a result of collaborative efforts between many different researchers, NGOs, protected area authorities and museums that have provided information.

2.1. Evidences of tropical rainforests and refugia

Boundaries of the tropical rainforest have constantly changed in response to climatic changes and geomorphological, geological, hydrological studies provide evidences (Hill & Hill, 2001). Evidences of the extent of the past rainforest are obtained from fossil flora and recorded occasionally on sampling sites (Couvreur & Baker, 2013). A statement from Hooghiemstra (2002) indicates that sediment cores from lakes are the best 'archives' to learn about the past of in the rainforest. Fossil pollen grains are accumulated in the sediments and conserved for millions of years where the changing pollen spectra in time document the floral and environmental history.

Muller (1981) noted that the fossil records of taxa characteristic of wet tropical forest started in the Late Cretaceous and since this period different families appeared in different geological era. In the Early Paleocene (60 My ago), closed-canopy tropical rainforest became widespread for the first time and occurred on all continents. After the cooling at the end of the Eocene, the distribution of closed canopy tropical rainforest in the Oligocene (30 My ago) was reduced to central and northern South America, central Africa, and too much smaller areas in Southeast Asia, India and Australia. At Middle Miocene thermal maximum (c.13 My ago, the area covered by tropical rainforest had expanded again (Hooghiemstra, 2002).

Maley (1996) proofed by the paleobotanical research that various tropical vegetation patterns developed through central and northern Africa from the Cretaceous to the end of the Tertiary, and has particularly elucidated several stages in the development of the rainforest.

Tropical rainforest declined in cooler climate but also predominantly drier in the Pleistocene glacial periods (ca. 100,000 year per cycle) and expanded in the warmer, wetter interglacial periods (ca. 10–20,000 year per cycle). This resulted in rainforests fragments and refugia in Africa and Australia where there no recent evidence to support that the neotropical forests promoted lineage differentiation and allopatric speciation that contributed to the extent of high tropical plant diversity (Rachel, 2014). A study on the vegetation dynamics in Central Africa since 18,000 y BP based on pollen records from the inter-lacustrine highlands of Rwanda, Burundi and Western Uganda did neither support a significant extension of east Central refuge onto the eastern flanks of the Albertine rift nor refute the possibility that such a major refuge existed in what is now the democratic Republic of Congo (Jolly *et al.*, 1997).

The "Refuge theory" suggested that more arid climates during recent glacial periods caused speciation by repeated fragmentation of the ranges of rainforest species (Pennington *et al.*, 2017). Furthermore, in a statement, Morley (2009) hypothesized that in some periods, frosts that may have occurred within the tropical zone and forced the tropical rainforest to refuges along the equatorial belt maxima and during the warmer periods in the Tertiary and the Cretaceous, much of midlatitudes would have been frost free.

To learn more about the past vegetation change and the modern distribution patterns Weber e*t al*. (2001) consider some factors the following factors: the tens of millions of years shaping the African rainforest system, the number of dry and humid climatic phases that affected Africa during the Pleistocene, the severity of the most recent glaciation maximum which might have contributed the strongest contemporary distribution patterns and the ability of each species or group to expend out of a refuge into favorable habitats (Weber e*t al*., 2001).

Fischer &Killmann (2008) emphasized that during the last glacial period (20000 B.C.), the climate was cool and dry and resulted in a lowering of the vegetation belts. Forests disappeared and humid forest survived in special refugia areas. According to these authors, the distribution patterns of some Afromontane species perfectly reflect these refugia and the mountain ridges around Kivu Lake including Nyungwe have been parts of such refugia.

2.2. Distribution of tropical rainforests

According to Morley (2009) tropical rainforests were first encountered when the Romans expended their empire to India and have become properly known for Western world only for the last few hundred years, since great voyages of discovery in the sixteenth and seventeenth centuries and the subsequent European colonial expansion. From the same author, the knowledge of tropical rainforest has come about a time when tropical rainforests are disappearing following commercial timber extraction, destruction for agriculture development and the expansion of human population across the World. At, present day, tropical rainforests are found in three areas within the tropical zone. They circle the earth around the equator (Lewis, 2006) and according to Morley (2009), found in the northern and southern high

pressure zones with convectional rain throughout the year and along eastern coastlines within the path of moist trade wind and where orographic uplift creates winter moisture.
All tropical rainforests were originally located between 23° and 27' N and the 23° and 27’ S. This area typically has a mean temperature of approximately 25°C with oscillations of less than 2-3 degrees and rainfalls over 1,500 mm a year (Leigh, 1999). They occur in Africa, Asia, and the Americas and are approximately 19 % of the world’s tropical rainforests, accounting for 184-200 million hectares.

The global distribution of tropical rainforest is presented on the **figure 4** and is based on information from NASA Earth Observations.

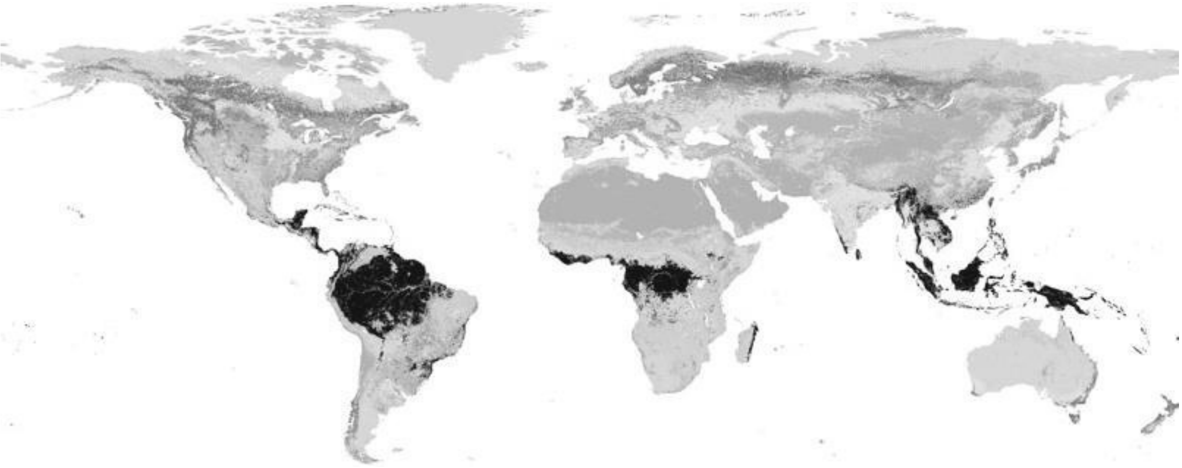

Figure 4: Global distribution of tropical rainforest (black) in 2003 (Hynson *et al.*, 2012)

2.3 African rainforests

Different authors described and highlighted rainforests of Africa. Richards in Nyandwi (2008) suggested that rainforests are characterized by a gigantic amount of rainfall with a minimum amount of rainfall of 1750 to 2000 mm per annum. This allowed later to identify many valuable biomes in Africa. These include, dry open forest, savanna and grassland biomes, mangroves, afro-montane ecosystems and others according to Malhi *et al.*(2013) and the same author reported that “a key feature of African rainforests is the strong effect of past disturbances by both climate change and human activity’ (Malhi et al., 2013)
The largest biogeographic unit accounts for 95% of African rainforests, the Guineo-Congolian forests of West and Central Africa. The Central Africa accounts for 89% of African rainforests

while the East Malagasy (Madagascar) and Afromontane (Central and Eastern Africa) have received less attention (Malhi et al., 2013).

It is well established that a rapid population growth with extreme poverty and political instability in common characterize the rainforest countries of Africa (Corlet & Primack, 2006) and result in armed conflicts with additional negative impacts on the rainforests (Matsuura, 2015). The African wet tropics accounts for roughly 30% of the global rainforest covers, a green heart of an otherwise a dry continent (Malhi *et al.*, 2013).

The roots of modern African rain forest can be traced back to the late Jurassic or lower Cretaceous (136 My), when the continent of Gondwana was beginning to split along the Africa and South America tectonic plates. In these rainforests, the dominant trees were Gymnosperms. While the African and South American tectonic plates gradually moved apart, numerous lagoons formed and the marine influence developed gradually (Weber *et al.*, 2001). By the Senonian, the Atlantic Ocean was opening up. The climate became wetter, favoring the radiation of Angiosperms and the decline of Gymnosperms in the tropics. The archetype of the modern African rain forest appeared as witnessed by Doyle, Salard-Cheboldaeff and Dejax in Weber *et al.* (2001). In Africa, the largest area lies in the Congo basin, the Sahel and extends westwards into Chad, Central Africa Republic, the Republic of Congo, Gabon and Cameroon. As a narrow strip, the evergreen forest continues further west, parallel to the coast of Guinea, through Nigeria and the Gold coast to Liberia and the Equatorial Guinea. This western extension is interrupted from western Nigeria to the Gold coast by a break in which the region of dry climate reaches southward to the coast. In the east, the rain forest scarcely reaches the region of Great Lakes. Southwards, the forest extends mainly as a post-climax gallery forest towards Zimbabwe according to the statement of Richards (1952). The rainforests are the great green heart of Africa (Malhi et al., 2013). In his review, Morley (2009) classified the African rainforests at the third rank with a fifth of the global total of neotropical rainforests and according to Fisher *et al.*(2013), the African rainforest biome constitutes the second largest rainforest region and include three African ecoregions. The Guineo-Congolian in West and Central Africa, the East Malagasy in Madagascar and the Afromontane in Central and East Africa. Although, the Afromontane ecoregion, Central Africa accounts for 89% and the DRC for 53.6%, East African countries with Afromontane forests (Ethiopia, Kenya, Tanzania and Uganda) represent only 2% of the rainforests (Descle *et al.*, 2013) and the vast central African rain forest is considered to be the least known of the World's tropical forest (Weber *et al.*, 2001). The African rain forest was relatively dry compared to other continents and receives between 1600 and 2000 mm of rainfall per year (Tucker *et al.*, 1985) but there were areas receiving more than 3000 mm per year as reported by White in Tucker *et al.* (1985).

2.4 Rainforest functions

Gay (2001) identified tropical rainforests as vital parts of Earth's supporting systems under which they play many ecological functions. In this review, they are only considered in three ways where brief details are provided.

2.4.1 Rainforests as stabilizer for the global climate

Forests are interlinked to climate change as they are envisaged in climate change mitigation. The tropical forest biomass stores high density of carbon but it is unfortunate that they continue to be subjected to a high rate of deformation resulting in all net emissions. Tropical forest store more than double the amount of carbon emission accumulated so far from human activities (Goodman & Herold, 2014). Tropical rainforests are characterized by the similarity of the habitat around the World. It has been observed a similar productivity in lowland rainforest reflecting the similarity of the climate due to evapotranspiration and seasonality in transpiration rate. In addition to that, in montane rainforest, the saturated climate is also related to the transpiration rate (Leigh &Egbert, 1975).

Furthermore, Nsabimana (2016), in his thesis argued that forest are important to reduce or stabilize atmospheric greenhouse gases and to mitigate climate change and they constitute potential strategies for conservation and sequestration of Carbon.

In a statement of the study on global biogeophysical interactions between forest, authors argued that the forest cover has a significant effect on climate and a dense forest has lower albedo than grasses because the forest canopy capture more irradiation (Brovkin *et al.*, 2009). Gharahi Ghehi *et al.* (2012) established the linkage between $N0_2$ and N0 emissions, which key elements in atmospheric chemistry for and climate variations in Nyungwe rainforest and it was found that the emissions were in the range the others reported for African tropical rainforests with special variation and affected by the soil water content in tropical rainforest.

Farooqui *et al.* (2010), in a study done in Southern India, demonstrated that the climate influence rainforests and argued that long-term persistence of moist climates have facilitated the continuity of many ancient rainforest flora. In contrast, climate is coupled with deforestation because deforestation modify the local and the regional climate and according to Malhi & Wright (2004), the future of World's tropical rainforests will not be determined by the climate trends but by the anthropogenic actions on the use and protection. In addition, while considered as “lungs of earth” and as “sweat glands “, Tropical forests deforestation and potential impacts have been analyzed from several studies and Lawrence & Vandecar (2015), hypothesized that a continuous deforestation of tropical forests would result in shifts of rainfall distribution and temperature.

2.4.2 Richest biodiversity habitat

Tropical rainforests are not monotonous equivalent biomes in terms of their structure and species diversity. They differ in terms of environmental and evolutionary history, regional and local climates, relief, soil and hydrology as stated by Bowman in Hill & Hill (2001) and Denslow (1987).

The spatial heterogeneity in tropical rainforests results in many habitats and each species is specialized at exploiting a particular sub-division of habitat. Thus, the diversity is viewed as a function of the total range of habitats (Hill & Hill, 2001). Zakaria *et al.* (2016) argued that the animal diversity and depends directly or indirectly on the support of the diversity in vegetation structure and composition of the tropical rainforests. This diversity is greater than in any other vegetation type. Its intrinsic value is much greater than that of temperate forests. Tropical rainforests contain an immensely large gene pool for the long future of animal and plants on this planet according to Morley (2009). They are the richest forests in tree species on the earth with large leaves trees and buttresses, climbers, epiphytes and hemi-epiphytes (Zakaria *et al.*, 2016). Epiphytes are common and dominated with orchids, ferns, bromeliads and bryophytes. They change in vegetation structure with altitude due to adiabatic cooling, wind exposure and soils characteristics in montane rain forests.

According to Hill & Hill (2001), tropical rain forest have a high diversity at family and genus level which indicates more ancient speciation. Thomas & Baltzer (2002) claimed for example that lowland evergreen rainforests have very high species diversity with over a 1000 of tree species in Amazonia and Southeast Asia with a canopy and emergent tree having a large spreading canopy over than 20 m radius at maturity.

Africa is the origin of humanity. African rainforest have evolved in the presence of hominids and their ancestors with the threatening effects (Malhi *et al.*, 2013). The Nyungwe forest represents an afro-montane rainforest and is one of the most threatened forests by human activities. It has a unique variety of flora, accompanied by an equal variety of fauna, including several species of birds and primates. A high percentage of these species are endemic and are found only in the forests surrounding Albertine Rift (Ministry of Lands Resettlement and Environment, 2003).

2.4.3 Rainforests “Centers of Biodiversity”

Wet tropical forest harbors the richest community of organisms on earth (Harms & Sheil, 2016). In the conference of the parties to the United Nation’s Convention on Biological Diversity (CBD) in 2002 at The Hague, a Global Strategy on Plant Conservation (GSPC) with two targets was adopted. Firstly, to protect 50% of the most important centers of plant diversity and secondly, to conserve 60% of the most threatened species of the world *in situ* by 2020. For a better achievement the mapping approach (Barthlott *et a*l., 2005) was used as presented below at figure 5. The World map of plant diversity shows a general increase of plants’ richness towards the equator. Global centers of species richness are concentrated within the humid tropics as presented on a map by the number of species per 10,000km^2(Barthlott *et al*., *op.cit*).

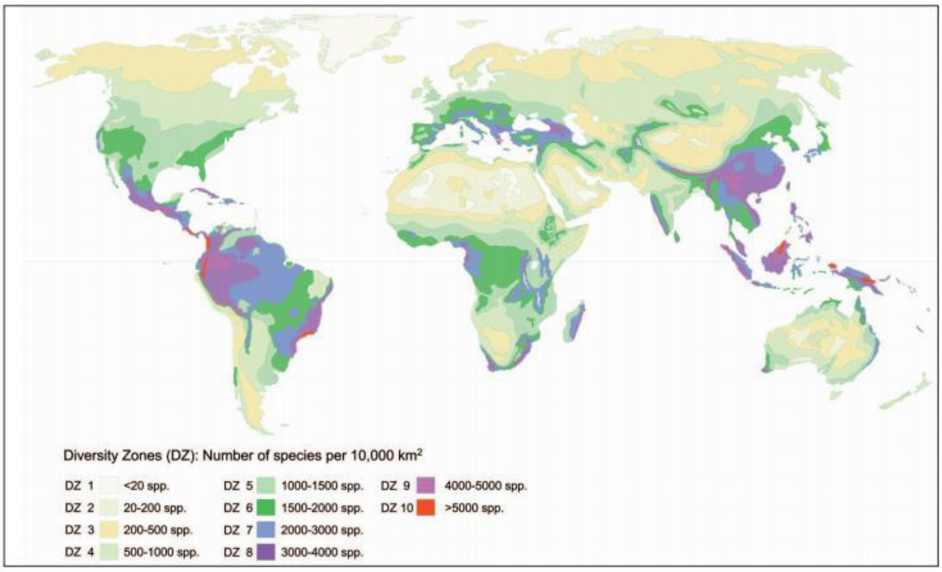

Figure 5: Global Center of plant diversity (Barthlott *et al.,* 2005)

The above map shows areas in the tropics with species richness with of more than 3,000 plant species per 10,000 km2 which are comparable to some parts of Central Europe. There are 20 centers of diversity characterized by high species richness, of which five fall into the highest category with more than 5,000 species and belong to the mountainous region of the humid tropics (Barthlott *et al.,* 2005). A study that analyzed the relationship between the continental scale of biodiversity and African plant distributions observed that the area of species richness occurred across the low latitudes and at the western tip of South Africa and more precisely across southern Ghana, Cameroon, Gabon, through the Eastern Arc Mountain region. The highest richness occurred in the Cape Province and species richness tended to correspond to mountain ranges of Eastern Mountain region and the Albertine rift system, areas of maximum rainfall.

The centers of species richness and endemism tended to have similar locations (Ferla *et al.*, 2002) and Jolly *et al.* (1997), previously recognized for the Central Africa two main centers of diversity, so called "core areas", located in the mountainous parts of the region. The first is located in the central west, namely Cameroon/Gabon, and the second in the lacustrine highlands bordering the Albertine rift, the later extending from Lake Albert in North down to Lake Tanganyika in South encompassing the Democratic Republic of Congo, Uganda, Rwanda, Burundi and Tanzania (Barthlott *et al.*, 2005).

2.5 Disturbance and threats to rainforests of Africa

Malhi *et al.* (2013), in their review stated that the African rainforests have been influenced by both the climate and human activities. It's reported that in Western Central Africa, a dense rainforest has been replaced by a forest-savannah mosaic in a period of 2,600 year age, a crisis which was first thought to be attributed to climate change and human expansion in the region but detectable traces in the sediments confirmed that human altered the rainforest ecosystem (Garcin *et al.*, 2018). In addition, Ponce-Reyes *et al.*(2017) using a simple ecosystem based modeling approach to assess the impact of climate on the seven main ecosystems of the Albertine Rift found out many of these ecosystems were seriously vulnerable to future climate change with a predicted decrease in extent and a shift in altitude from 2050. The role of climate change has been also depicted and found to have an implication on Africa rainforests. According to predictions, precipitations will increase in East Africa while decreasing in Western Africa and in Equatorial Africa, large increases in dry season water deficit in response to the global warming, with severe consequences on Africa rainforests (James *et al.*, 2013). Furthermore, climate change has been qualified as an 'insidious threat that can quickly and profoundly modify the functioning and the dynamic of rainforests,

Douglas (1999) coted "anthropogenic influences are ubiquitous. Human actions have affected the most natural and pristine systems" and added that each site has a history which the explanation of the present and an evidence of the future. There is a large array of rainforests threatening activities. They include in one hand, those responding to direct needs of people like food, medicines, shelter, settlement… and indirect needs in another hands, like public infrastructures (schools, hospitals, roads...). In a study, it has been concluded that roads cause a variety of fragmentations in rainforests with among others habitat loss and alteration, edge and disturbance effects and this create subdivisions of the population of fauna and flora (Goosem, 2014). The habitat fragmentation is also a driver of loss of genetic resources and shape the structure and the distribution of lianas in tropical rainforests (Addo-Fordjour *et al*., 2012; Addo-Fordjour *et al*., 2013). Alroy (2017) estimated that some and many species may have already gone extinct because of the complete deforestation of their ranges or gone extinct in intact tropical forest because of stressors such as hunting, invasive species, introduced epidemic diseases and the direct effects of climate change. Moreover, Gorte & Sheikh (2010) previously reported that there are benefits in reducing deforestation which include among others biodiversity preservation, providing livelihood to rural populations living in poverty and sustaining indigenous communities.

2.6 Rainforest of Albertine rift region

According to Kanyamibwa (2013), the Albertine Rift is the western branch of the African Rift valley which extends from the northern tip of Lake Albert to the southern tip of Lake Tanganyika and crosses the borders of following six countries: the Democratic Republic of Congo in the east, Uganda in the west, Rwanda, Burundi, Tanzania and Zambia in the North. ARCOS definition considers Albertine rift as a bioregion which including the Albertine Rift ecoregion and the ecological, physical, political and cultural systems within and around it. This region includes the volcanic mountain massifs including active Virunga volcanoes, biodiversity diverse montane forests, great lakes river systems and savannah habitats. The region contains the third highest montane in Africa (Ruwenzori's mountains), the second deepest lake in the world (Lake Tanganyika) and the most endangered great Apes in world (Mountain gorilla, *Gorilla beringei*) according to Kanyamibwa (2013). A current definition of Albertine rift by Plumptre *et al*. (2007), includes all natural habitats within 100 km east of the border of the Democratic Republic of Congo and follows 900 m contour line in eastern democratic Republic of Congo and in northern Zambia as there are museum collections of Albertine rift birds endemic species at the Africa Museum in Tervuren, Belgium that were found as low as the 900 m of altitude. The Albertine rift covers more than 300,000 km^2 in Central East Africa and its montane forests are centers for geologic activity and innumerable endemic species facing the effect of the highest human pressure trend in eastern and central

Africa recovering from decades of conflicts (Dino, 2013). Barthlott *et al.* (2005) estimated that in this area, the natural vegetation types incorporate the very eastern portion of the Guineo-Congolian rainforest in the lowlands as well as Afromontane and ericaceous vegetation above 600 m while the Afromontane ecoregion type harbors highest species richness and a highest concentration of endemic species.

It is assumed that the Albertine Rift is one of the most threatened sites for biodiversity conservation and being home to 7,500 of endemic plants and animal species. At some locations, it is the most populated region with up to 600 people per square kilometer. The human population pressure together with the flow of refugees and lack of settlement policies has resulted in forest degradation, fragmentation and loss of 52,000 km² in protected areas (Plumptre *et al.*, 2007). According to Dino (2013), all the factors above combined constitute one of the key priority areas for conservation and sustainable development.

2.6.1 Rainforests in Rwanda

The natural ecosystems of Rwanda are mainly composed of mountain rainforests. They comprise Nyungwe National Park, the Volcanoes National Park and Gishwati-Mukura recognized recently as a National Park in February 2016 (RDB, 2017). They are part of Albertine rift afro-mountain forests and constitute an important habitat for biodiversity and ecosystem services (MINITERE, 2003).

Research results of a study conducted using remote sensing on Nyungwe-Kibira forest has revealed a severe fragmentation outside and a slight fragmentation inside the park (Keenan *et al.*, 2015). Cyamudongo forest, a disconnected forest patch at a distance of around 8 km from Nyungwe National Park (Mvunabandi *et al.*, 2015), is part of Nyungwe National Park. The protection and conservation of Cyamudongo were promulgated in 1985 and a buffer zone of 25 km^2 made up of exotic species like *Pinus patula* and *Cupressus sp.* was established along the northern and southern part of the forest (Gapusi, 2007).

2.6.2 Nyungwe rainforest

Plumptre *al.* (2002) emphasized that Nyungwe was gazetted as a forest reserve in 1933, however, people continued to utilize the natural resources of the forest which resulted in local extinction of major wildlife species, especially large mammals like elephants and buffalos. It has been used for a wide range of economic activities including gold mining since 1935, honey collection, woodcutting; hunting of animals and small-scale agriculture.

Nyungwe National Park (NNP) is a montane rain forest in the Southwest of Rwanda and covers an area of approximately 1019 km^2, including the forest fragments of Gisakura and Cyamudongo (Moore *et al.*, 2018). Nyungwe National Park is among the most diverse and important montane forest in East Africa and it is famous for its diversity in primates, birds and plants. Fischer & Killmann (2008) qualified the flora of Nyungwe as unique with 47 locally endemic flowering plants and about 280 Albertine Rift endemics.

With an altitude range between 1600 to 2950 m sea level for Nyungwe and between 1500 and 2100 for Cyamudongo (Chitayat, 2015), Nyungwe National (NNP) is inhabited by some of the rarest and endemic species of wildlife such as owl-faced monkey and chimpanzee Pan-troglodytes (Plumptre, 2004). Munanura *et al.* (2017) designed the important attribute of the NNP to be the concentration of the Angolan black and white Colobus in large groups over 400 individuals which a rare phenomenon that conferred to the park to be considered as one of the most sites for biodiversity conservation in Africa. The periphery of the NNP is settled predominantly by subsistence farmers and tea plantations (Gross-camp *et al.*, 2015). Mlotha (2018) discussed the decrease in vegetation cover prior 2003 as an indicator that there had been a combination of natural and anthropogenic on forest and natural resources. The active mining where the topsoil was removed and some trees dug out and left vulnerable to blowing winds.

According to Weber (1989), between 1958 and 1979, the forest reserve has been reduced from 1,141 km2 to 971 km2 due to encroachment by local farmers. The management plan of NNP of 5 years was dedicated ‘to protect the biodiversity of NNP and maintain its ecological services for the benefits of the neighboring local community, the country and the global community’ (Rwanda office of Tourism and National Parks, 2006).

Weber *et al.* (2001) recommended in their research about African rainforest ecology and conservation series of tools as steps in developing farsighted conservation plans for forest sites by obtaining sufficient information as possible about the natural range of variation in local vegetation communities over long time periods. Moreover, the aspect of paleoecology must be involved in generating information about the response of the forest at a particular site to known climatic changes in the past. Thereby charcoal, plant macrofossils and pollen can help to draw conclusions on the nature and degree of stability of local vegetation.

According to Mildbraed (1907) in Fischer & Killman (2008), Nyungwe National Park has an enthusiastic impression with beauty; its species richness makes it the richest mountain rainforest of Africa that tourists can experience. Mecklenburg, a botany explorer, stated in 1910 that the forest of Rugege (former name of Nyungwe National Park) was attractive as any forest in Usambara, along the Uganda railway or on the Mau plateau. Due its abundant vegetation entirely new in the beginning of exploration, Nyungwe was found to be oppressive and with a splendid magnificence (Fischer & Killman, 2008).

Since then, there has been a good progress in the generation of the knowledge about the biodiversity of Rwanda in general and particularly of Nyungwe forest. For instance, Georges Troupin worked intensively to describe and determine the diversity of flowering plant species of Rwanda which resulted in four volumes of "Flore du Rwanda, Spermatophytes, Volume IV, III II, & I (Troupin, 1988; Troupin, 1985; Troupin, 1983, Troupin, 1978). Additionally, he wrote "La Flore des Plantes Ligneuses (Troupin, 1982) that covers most of the species from Nyungwe forest. Troupin's work has been followed by several trips of exploratory searches led by Eberhard Fischer throughout the country which allowed to discover and describe new species for Rwanda and for Sciences. The most important achievements include: "Aperçu sur la flore et la faune du Rwanda" (Fischer & Hinkel, 1992) and the illustrated Field Guide Plants of Nyungwe National Park. At a regional scale epiphytes vegetation and ecology in central Africa (Zaïre, Rwanda) forests has been subjected to analysis (Biedinger & Fischer, 1996) while more recently, discoveries of new plant species culminated in the family of Balsaminaceae (Fischer *et al.*, 2003) and Orchidaceae (Fischer *et al.,* 2010). The species number in these families increased approximately to 250 and 16 respectively (Fischer *et al.*, 2010).

Seimon (2012) in his report emphasized on the role of Nyungwe for biodiversity conservation and for the national socioeconomic interests from which climate change become a challenging issue for the future. Climate change impacts negatively on Nyungwe landscape by exacerbating existing threats to species and human population depending on Nyungwe Ecosystem services or by introduction of new ones.

2.6.3 Cyamudongo fragment forest of Nyungwe National Park

Cyamudongo forest used to be connected to Nyungwe National Park, but today the two forests are separated (Kanyamibwa, 2013). It captures some lower altitude habitats which are not found in the main forest block of Nyungwe (Plumptre *et al.*, 2017) and today, Cyamudongo Natural forest is located a way at a distance of at least 8.5 km horizontal distance to Nyungwe main block.

The Cyamudongo patch of NNP has retained less attention so far. Few studies were directed to primates. Mvunabandi *et a*l.(2015) concentrated his studies on the Eastern Chimpanzee's fragmentation habitat in Nyungwe National Park and evaluated fragmentation patterns for a period of 25 years whereas Cyamudongo appeared to be an isolated chimpanzee's habitat. A previous study directed on chimpanzees concluded that environmental degradation and changes in animal behavior result from tourists visit to fragile ecosystems. It claims that the potential for negative impacts of tourism is exacerbated by small areas like Cyamudongo forest (Krajewski, 2007). Chitayat (2015) stated in her thesis "Living in a Fragment: The Behavioral Ecology of Chimpanzees (*Pan troglodytes schweinfurthii*) in Cyamudongo Forest, Nyungwe National Park, Rwanda" the need for an assessment of F*icus* diversity. Ficus species dominate the diet of chimpanzees in Cyamudongo and their persistence is most important for this vulnerable habitat.

2.6.3.1 The origin of the name Cyamudongo and etymology

The current Cyamudongo forest was known before under Bukunzi forest, with the highest elevation culminating with Cyamudongo and followed by Rwankovu. The fact that Cyamudongo was the highest summit where it was observed the preliminary signs of rain-periods to come such as pincher ants and excessive increase of temperatures, dedicated the current name Cyamudongo to the entire fragment forest (Gakwaya, pers. com.).

2.6.3.2 Historical background of Cyamudongo, fragment of Nyungwe

Born in 1941, Frederick Gakwaya was born in 1941; former Bourgmestre of the commune Bukunzi and grew up within Bukunzi Kingdom where Cyamudongo forest reserve is located today. Gakwaya's family was living around the Cyamudongo forest, had farms around there and he used to go to prevent animals from damaging family crops. Moreover, people used the forest for firewood collection for Kamembe market to earn money. The separation of Cyamudongo with Nyungwe forest reserve was caused by the population from other regions of the country that came to search place for residence. Criteria for settlement places were the accessibility and suitability for daily living conditions to people and their livestock. Nyungwe forest had gained their preference. The political revolution and the venue of political parties in 1959 were followed by 'Ubukonde' where people used to take several hectares of the forest and transform them into farmland. Around 1963, the leadership of the time decided to stop people from encroaching Nyungwe and Cyamudongo forest reserve. But the forest was the property of chieftaincy of Bukunzi in Impala Kingdom and the colonial administration till the 1962 independence (Gakwaya, pers. com.).

Nyungwe is one of the most biologically important montane forest systems in all of the Central Africa, a biodiversity hotspot first gazetted as national reserve in 1933 and elevated to rank of a national park in 2002 according to Rutagarama & Martin in Chitayat (2015). The later confirmed that while Cyamudongo was formerly managed by Bukunzi District, it became part of Nyungwe National in 2004. Very high human population density adjacent and around the park threatened the biodiversity of NNP by extraction of natural resources for food meat and plants, building materials, raw materials, etc.… Cyamudongo was isolated during 1960s and from this period until 2000 (Chitayat, 2015) and Nyungwe forest lost an estimated 80% of forest cover (Rutagarama & Martin, 2006) due to increasing population pressure. The forest was converted into farmlands, agricultural lands as well into tea plantation. Cyamudongo forest progressively reduced in size up to 410 ha of its natural forest remaining today (Mvunabandi *et al.*, 2015b). But, in the "Illustrated Field Guide to the Plants of Nyungwe National Park, Rwanda" by Fischer & Killmann (2008) as well as Kanyamibwa (2001) and Musabwamana (2019), estimated with unanimity Cyamudongo at 300 ha.

Cyamudongo fragment lower mountain forest extends over five hills surrounding the valley of the river Nyamabuye the valley of the river Nyamabuye between 1.500 and 2.140m alt isolated since at least a 100 years according to Fischer & Killmann (2008) and which remains a locality where many species find only their locality in Rwanda or even in the World (Fischer *et al.*, 2010).

The map at the figure 6 presents Cyamudongo with reference du Nyungwe main bloc.

Figure 6: Location of Nyungwe and Cyamudongo, obtained from satellite image via https://www.google.com/earth/versions

2.6.3.3 Soil characteristics of Cyamudongo and Gasumo study area of Nyungwe National Park

Gharahi Ghehi *et al*. (2012) suggested the soil to be the level two important source of N_2O and NO that influence the chemistry of the atmosphere and a factor of changes in climate. Nyungwe soils have been previously estimated to be similar to soils of Kakamega (Kenya) rainforest and the Mayombe (DRC) forest soils as a result of comparison of ther average content of salt, gray and OC almost similar according Werner *et al.* in Gharahi Ghehi *et al*. (2012) and later generalized on African tropical rainforest. Soil attributes such edaphic composition, topography, acidity and variability and agrophysiological behaviour or soil morphology are key determinants of species composition, richness and distribution and moderate all forest features (Sellan e*t al*., 2019; Buringh, 1981).

There are a range of soil classification systems on the basis of soil survey in temperate and tropical regions and based on soil properties which came up to determine five soils bodies to be broadly distinguished in level of soil classification and FAO classification system has been the mostly used to classify soils in Cyamudongo and the study area of Gasumo (Driessen *et al.* 2001). A map acquired from the satellite image showed that there is a difference in the soil classification between Gasumo study area of Nyungwe and Cyamudongo, soil profiles. The soil profile at Cyamudongo is found to be dominated by Cambrisols followed by Ferralsols, Regosols while Acrisols are poorly distributed.

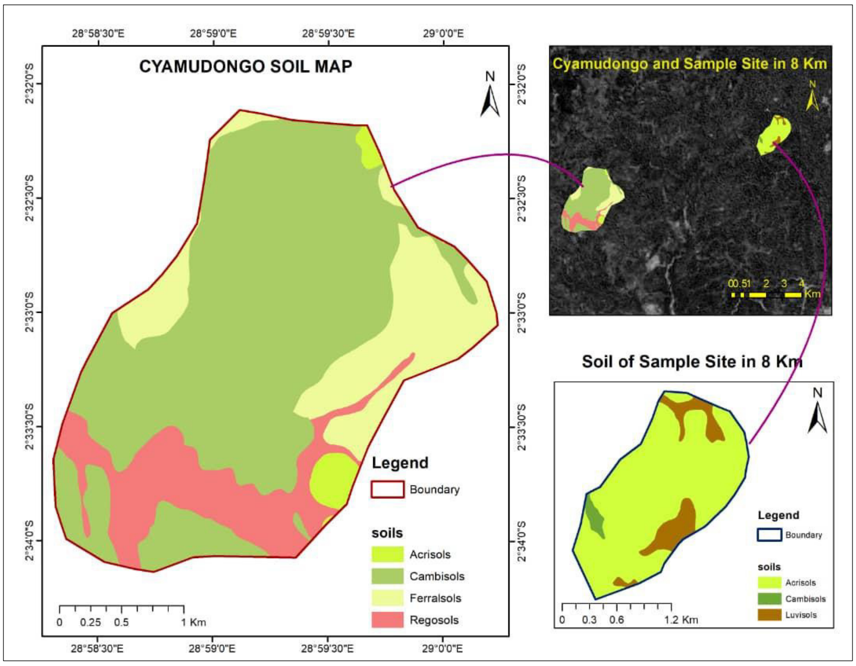

Figure 7: Map of soil characteristics of Cyamudongo and Gasumo, study area of Nyungwe

Map obtained from satellite image with the support of Mwizerwa Fidèle.

On the other hand, Acrisols with a little presence at Cyamudongo dominate in Gasumo followed by Luvisols and a poor presence of Cambrisols as presented on the map at figure 7. The presence of these soil profiles has been previously suggested by IUSS Working Group WRB, Verdoodt and Van in Ghehi *et al.* (2012) in tropical rainforest of Rwanda. The soil groups identified at the studied are described as follow according to Driessen et al.(2001) and mentioned to characterize six tropical soils according to FAO in Verdoodt & Van Ranst (2006) and Ghehi *et al.*(2012).

Acrisols: the Soil Group of the Acrisols accumulate low activity clays in an argic subsurface and are characterized a low level of base saturation and known to distributed in West and East Africa. Cambisols moderated developed soils due to rejuvenation of the soil material and made in all environments from and in different vegetation types.

Ferralsols known to be classical, deeply weathered, red or yellow soils of the humid tropics. Horizon boundaries of these soils are not differentiated with a clay assemblage with a low activity clays and a high content of sesquioxides.

Regosols are soil groups with shallow, sandy texture and often existing of sloppy topography and mostly in dry areas and highlands as argued by Masiga (2010).

2.6.3.4 Weather conditions: temperature and rainfaill

According to Moore *et al*. (2018), the park receives more 2000 mm of rain annually primarly during the two wet seasons (March to May and from September to December).

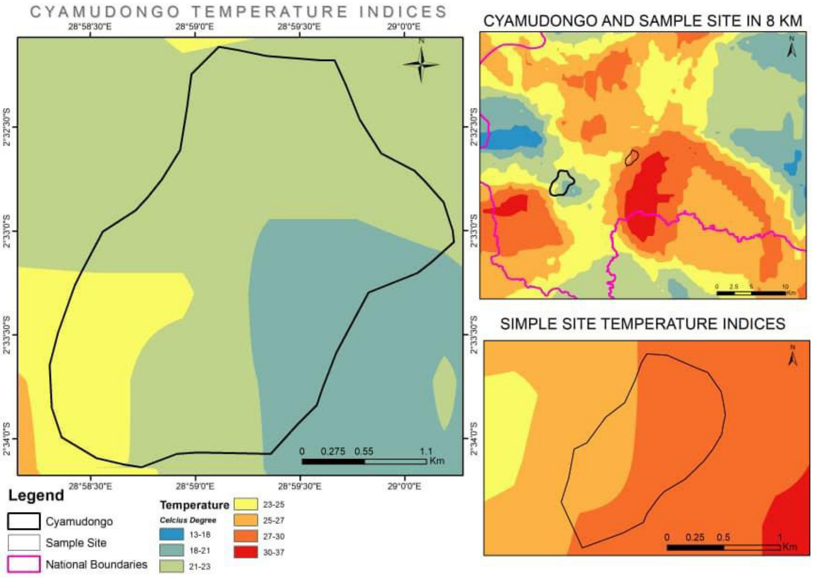

Figure 8: Temperature indices of Cyamudongo and Gasumo, study area of Nyungwe

The temperature varies little throughout the year, with average minimum and maximum temperatures of 10.9°C and 19.6°C, respectively. In the study of Seimon (2012) argued that the climate of Nyungwe is known to be a typical tropical mountain forest with a very small termal seasonality with a long wet season from May to September and much drier conditions during the mid year months and average rainfall between 1500-2500mm

Although, these weather conditions presented different figures at Cyamudongo and the study area of Nyungwe main block as depicted at figure 8 for annual temperatures and figure 9 for annual rainfall. For instance, the temperature indices at both studied areas are the lowest at Cyamudongo than at the study area of Nyungwe main block where the temperature varies respectively between 18-25^{0}C and 25-30^{0}C for Cyamudongo and the studied areas of Nyungwe and the north and the southern west of Cyamudongo bearing lowest temperature indices.

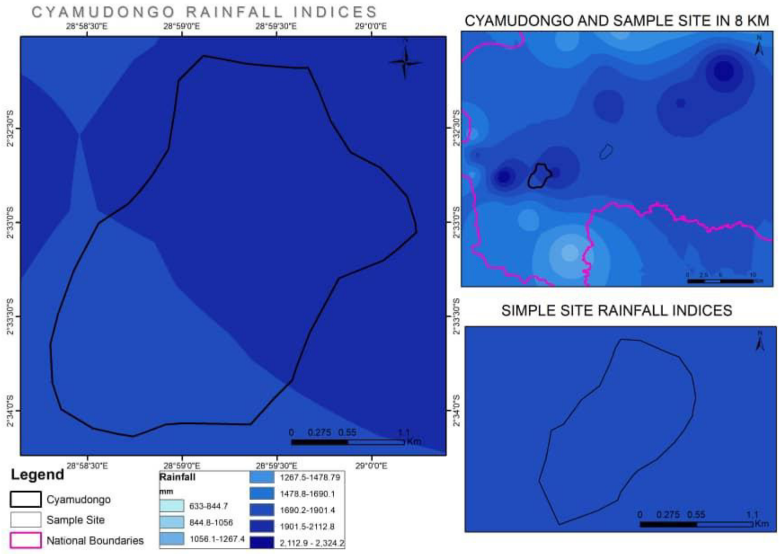

Figure 9: Rainfall indices of Cyamudongo and Gasumo, study area of Nyungwe

At the other hand, the middle and the north-est of Cyamudongo and the study area of Nyungwe receives almost the same quantity of rainfall ranging between 1901.5-2112.8mm while the southernwest of Cyamudongo receives lower rainfall. A knowlege of the distribution patterns of temperatures and rainfall regime can be useful to understand the forest structure and composition of Cyamudongo and the studied area of the Nyungwe main block.

2.6.4 Physiognomic landscapes forests in Cyamudongo rainforest

In this study, the patterns of flora diversity are investigated in buffer zones, secondary and primary physiognomic communities of Cyamudongo and the western block of Nyungwe main forest were compared and analyzed.

2.6.4.1 Primary forest landscape

Kormos *et al*. (2017) assumed that primary forests are naturally regenerated forests of native species with no indication of human activities that disturbed ecological processes. According to FAO in Kormos *et al*. (2017) these forests are characterized by natural forest dynamics in tree species composition, occurrence of dead wood, age structure, and natural regeneration processes. They cover a large enough area to maintain characteristics and species composition. The natural primary forest provide refuge to endemic species and rich biodiversity (Cole & Dyszynski, 2011). According to the definitions above, in Nyungwe and Cyamudongo forest differ primary and secondary forest due to the presence of indicator species. *Syzygium guineense* and *Macaranga kilimandscharica* are very important indicator species for secondary forests (Mlotha, 2018).

2.6.4.2 Secondary forest landscape

Chokkalingam & Jong (2001) argued that a secondary forest correspond to the successional forest stages that develop after the destruction of the original forest and is completed, when they develop again climax communities or primary forests. After a review of several studies related to the subject by the same authors; secondary forests were defined by consensus as forests. After a review of several studies related to the subject by the same authors; secondary forests were defined by consensus as forests that regenerate through natural process after a nature or human led disturbance of the original forest vegetation at a single site in time or over an extended period, and displaying a major difference in forest structure and /or canopy species composition with comparison to nearby undisturbed primary forests on similar sites (Chokkalingam & Jong, 2001). Corlett (1994) considered secondary forests as a consequence of natural catastrophes which break forest continuity but with less extend result in modifies primary forest. Mlotha (2018) argued that 50% of Nyungwe National Park is a secondary forest while Mvunabandi *et al.*(2015) studying the chimpanzee's habitat fragmentation qualified Cyamudongo forest patch of Nyungwe National Park as a disturbed forest undergoing different successional phases with a dense vegetation and few clearings according to Kanyamibwa (2001).

2.6.4.3 Buffer zones landscape

The term buffer zone was thought to be relatively new and serves to avoid negative human impact on the conservation area. Ebregt & De Greve (2000) defined a buffer zone as area peripheral to the protected area in which activities are implemented or the area managed with the aim of enhancing the positive and reducing the impacts of conservation to neighboring communities and of neighboring communities to conservation. The forest buffers planted or natural are the oldest known buffer zones created for exploitation purposes. They are parts of natural forest converted into planted forests and the rest considered as core zones and the functional quality is best when they are extension of the core zone habitats (Ebregt & De Greve, 2000). According to Mackinnon in Sayer (1991), buffer zones have been defined as areas peripheral to national parks or reserves with restrictions resource and special development measures to give an added layer of protection and to compensate villagers for the loss of access to strict reserve areas. Nyungwe forest is surrounded by a buffer zone planted with different kind of *Eucalyptus* and pine trees (Gross-camp *et al.*, 2015). The Cyamudongo fragment forest buffer zone is under protection and planted with trees like *Pinus patula*, *Eucalyptus sp.*, *Cedrella serrata* and *Grevillea robusta* (Author, Pers. Com.).

2.6.5 Conservation of Cyamudongo rainforest

2.6.5.1 The initiation phase of conservation of Cyamudongo forest

Gakwaya administered Bukunzi commune in a period where some people used to exploit the forest even though it was illegal. Human activities within this forest mainly concentrated on hunting, timber and non-timber extraction for different domestic uses, tubers collection and harvesting of medicinal plants.

In the period of his administration (1971-1987), with the help of former Cyangugu Governor, Gakwaya established regulations to protect the forest: (1) It is prohibited to register a farm land surrounding the forest as own property, whoever who will disobey this order will be requested to pay taxes. (2) Everyone who cultivated in those farms surrounding the forest was subjected to pay taxes and if he/she refused the farm was taken by another person. This discouraged the villagers from violating the forest and fostering the acceptance that this forest is a governmental property. (3) Gakwaya in partnership with volunteers from Germany planted *Pinus* trees as a buffer zone of Bukunzi forest (Cyamudongo) which exists till now (Gakwaya, pers. com.).

Today, RDB has initiated a sensitization program for environmental protection to the community around Cyamudongo forest through arts and dances, shown by a founded cooperative of youth with the aim to educate people about the sustainable use of natural resources. The impact of revenue sharing of RDB with development of infrastructures such as roads, hospitals, schools contributed in raising awareness for the importance of Cyamudongo forest conservation (Gakwaya, pers. com.).

2.6.5.2 Cyamudongo forest project

The efforts to protect and conserve the biological diversity of Cyamudongo have been supported by international cooperation initiatives. In this case, the University of Koblenz-Landau initiated under Cyamudongo project, a program of protection and conservation around Cyamudongo entitled" Conservation of Biodiversity and Natural Resources and Climate Protection by Sustainable Agriculture and Forestry at Cyamudongo Forest" in Rwanda". The project is managed by the University of Koblenz-Landau and implemented in Rwanda by the Association for the Promotion of Sustainable Development in Rwanda, funded and supported through the International Climate Initiative of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety based on the decision of the German Bundestag.

The project recognized that in 2014, NNP and its adjacent Cyamudongo forest, became, legally protected as a National Park limiting interventions but the pressure on natural resources remained very high. Agricultural plots are found situated at every edge of the forest with unsustainable land use practices resulting in soil erosion and degradation and the production of wood is insufficient to cover the needs of the fast growing population in the area (University of Koblenz-Landau, 2019).

The project aims to contribute to the protection of the biodiversity and geo-ecological functions of Cyamudongo forest. It strengthens also the awareness of the population about biodiversity and ecosystem services of the forest and contributes to the capacity building of smallholders. It also wants to achieve an agroforestry systems and small semi-natural forests that prevent a further degradation and erosion of the soils. These trees and shrubs produce additional biomass that contributes indirectly and directly to increase agricultural and forestry production. Hence, the project makes a contribution to the food and energy security of the local population. At the same time the project reduces the human pressure on the resources of Cyamudongo forest, and therefore it maintains as an important carbon sink. The project outcomes and lessons-learned will be translated into recommendations for the conservation of mountain rain forests.

2.7 Consequences of Cyamudongo deforestation

In view of the facts that resources are overexploited, some plants and animal species were extinct within this area. Examples for animals are antelopes, rabbits and hyenas while many plant species like should have been extinct and other like *Alangium chinense, Newtonia buchananii, Symphonia globulifera* and *Entandrophragma excelsum* have been reduced in population to isolated trees. With proceeding deforestation of Bukunzi forest, the temperature rose increasingly and caused the disappearance of low temperature friendly crops and wild plants. In the past, there were abundant precipitations and prosperous crops in this region. It was even possible to cultivate crops like peas and sorghum or harvest bananas from uncultivated bushes without any further treatment there (Gakwaya, pers. com.).

The alteration of environment by human activities converted habitats into a mosaic of intact and disturbed land which resulted in extinction of a large population of animals (Adrienne, 2015). Julie (2006) recommended in his research about' the response of chimpanzees to habituation and human-chimpanzee encounters in Cyamudongo forest' that a habitat corridor between Cyamudongo and Nyungwe forest should be created in order to allow chimpanzee migration and gene flow between these two forests. This may not only increase the viability of the chimpanzee population but also of other animal and plant species. Even though, Cyamudongo has the great potential for a successful development of ecotourism without a proper management of population and residence is an effective maintenance and protection of the biodiversity and aesthetic of this forest unlikely (Adrienne, 2015).

2.8 Invasive plant removal in Cyamudongo forest

The proliferation of invasive was named among other threats to NNP (Gapusi, 2007). The degradation of Cyamudongo forest facilitated the introduction of *Solanum chrysotrichum*, known as giant devil's fig, a shrub that grows 2-4 m tall which reproduces mainly by seeds dispersed by birds and others animals that eat the ripe fruits which is considered to invade the natural vegetation in Cyamudongo (The freshwater consulting group & Wetland solutions, 2012). The plant is native to Mexico and Guatemala, but was naturalized in Eastern Congo and Rwanda. Lacking natural controls outside of its native range, it invades the margins and disturbed areas of rainforests and threatens the forest ecosystem. During regular monitoring surveys, the spread of the species was detected. Therefore, over a period of 4 weeks in 2019, intensive removal efforts were made by Cyamudongo project in collaboration with Rwanda Development Board (RDB), to prevent further spread of this invasive plant species in Cyamudongo forest. Results from this assignment will allow to develop a management strategy of *Solanum chrysotrichum* (University of Koblenz-Landau, 2019).

CHAPTER 3. MATERIAL AND METHODS

3.1. Research preliminary

Following a request of a research permit to access to the Nyungwe National Park to RDB Head of Conservation Department, a research agreement was signed every time before data collection starting in July 2017 for the initiation. A short reconnaissance survey was undertaken to get an overview of the area and discover Cyamudongo and the Western Nyungwe main forest block. The reconnaissance helped to identify physiognomic differences in Cyamudongo forest with following three types of vegetation: primary forest, secondary forests and buffer zones. On the basis of these vegetation types, the study plots were selected as presented at the map below (Fig.10& 11).

Data collection was done July 2017 until April 2018 and from December 2019 until February 2020 in Cyamudongo forest, a 4 km^2 forest fragment that is part of Nyungwe National Park in the southwest of Rwanda, East Central Africa according to Chitayat (2015) and extended collection in the western Nyungwe main block with characteristics described at **table 1** below.

Table I: Nyungwe and Cyamudongo physical and weather characteristics

Characteristics	Nyungwe	Cyamudongo
Geographical Position	2° 17´-2° 50´S	2°32’33’’S
	29° 07´-29° 26´E	28°58’-28°59’E
Altitude	1600-2950 m	1500-2100 m
Mean annual rainfall	1744 mm	1720 mm
Annual Temperature	10.9 °C -19.6°C	15-16 °C

(Kanyamibwa, 2013; Chitayat, 2015; Seimon, 2012; , Kamembe Meteorological station data).

The study area of Cyamudongo and the closest area of Nyungwe main forest

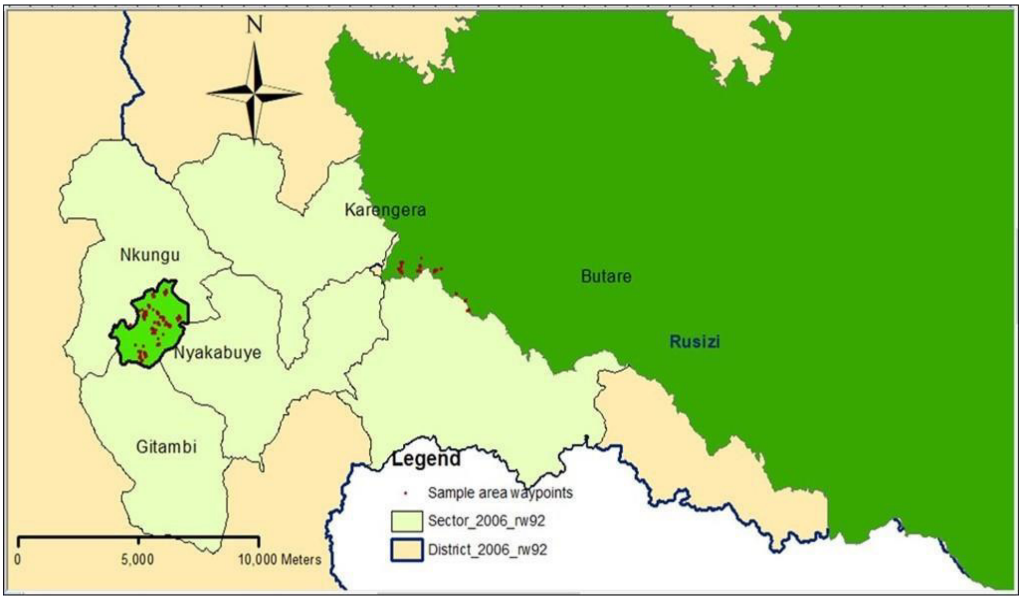

Figure 10: Map of studied sites in Nyungwe and Cyamudongo Forests

Source: 2006 shapefile for sectors and districts

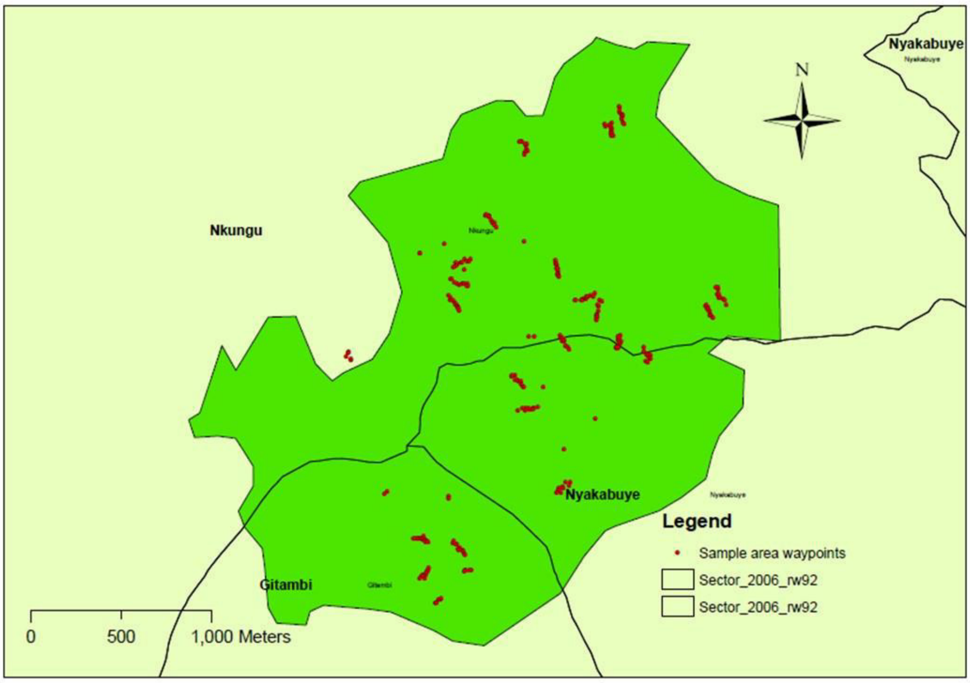

Figure 11: Map of the study area in Cyamudongo

Source: 2006 shape file for sectors and districts

3.1.1 Study design

Data collection was carried out in the forest relict, Cyamudongo, and in Nyungwe National Park. The existing trails in the forest were selected as baseline for setting perpendicular transects as used in the research of Mehrvarz *et al.*,(2016) in different forest types in the direction of the slope. Forty-five transects of 50 m long were established in Cyamudongo and fifteen in western main block of Nyungwe National Park respectively. At both sides along the line transect were every vascular plant recorded within 2 m distance. Consequently, the sampled area by each transect was 200 m^2 which is in line with the suggested size for sampling sites in tropical forests by Gillison (2006). A stratified sampling strategy that considers physiognomic differences among plant communities was used to establish fifteen transects each in primary forest, secondary forest and the buffer zones at both Cyamudongo and Nyungwe main forest block. In addition, plots were used to minimize heterogeneity within plots and maximize variability between plots as proposed by Dengler (2016) who suggested a sample area in the range of 4-25 m^2 for the herbaceous vegetation and 50-400 m^2 in woody vegetation.

Moreover, correlations between non-distanced sampling units along transects are often observed and subjected to underestimation of the standard error between plots according to Elzinga in Vanessa (2009). In the present study, fifteen and five permanent plots of 10 x 10 m^2 were established in each type of forest type in Cyamudongo and in western Nyungwe main block. These independent sampling units are used to avoid estimation errors for the good measure of similarities and differences between Cyamudongo forest types and Nyungwe nearest area of the forest as a sample unity. Transects and plots were set up with a measure tape and marked by ribbons.

3.1.2 Sampling and measurements

Different ecological parameters and vascular plant species attributes have been recorded for further uses in different statistical analyses as a tool for hypotheses validation. Data were taken using sheets with different header with distinct attributes and variables.

3.2 Vegetation sampling

The vegetation sampling was carried out in transects and permanent plots. Data were collected using the Braun-Blanquet cover-abundance to estimate community composition and species dominance (Braun-Blanquet, 1965). This phytosociological method allows to assess and determine the health of an ecosystem (Mehrvarz *et al.*, 2016) and is known to be suitable for synmorphological and syntaxonomical purposes (Chmura & Salachna, 2017). In this approach the species composition of an area allows to explain better the relationship between species one another and to their environment (Maarel, 1975). The Braun-Blanquet scale corresponds to a measure of species cover in percentage (%) as it has been applied later by Poore (1955) and Damgaard (2014) argued that the relative projected area covered by the species in other words the plant cover is a measure of the abundance that is useful in plant ecological studies. The appropriate cover-range was recorded in the field for each plant species as described below for the density measurement of trees, shrubs and herbaceous vegetation. Thereby the cover-range of each vascular plant species is described as follows:

Table 2: Plant cover-abundance scale

Scale	cover value/Cover%
R	Very rare, negligible cover
+	Small cover value
1	1–5
2	5–25
3	25–50
4	50–75
5	75-100

In this study, solitary species conventionally assigned an “R” were combined with those assigned a “+” (cross) rating. The species lists of each permanent plot and transect were prepared and compiled.

3.2.1 Canopy coverage estimation

The canopy coverage for each 4x10 m^2 plot along the line transect and 10x10 m^2 permanent plot was estimated and canopy coverage classes previously described by Hanley (1959) have been adopted for this study. Table **3** presents canopy coverage classes used.

The estimation the canopy cover in forest is referred to the statement that "within a forest strand, variation in a forest composition, structure and foliage distribution regulates the light transmittance in the understory, affecting the growth and mortality of seedlings and saplings" (Montgomery & Chazdon, 2001). A canopy cover is defined by Jennings in Kari (2006), as the proportion of the forest floor covered by the proportion of the trees crowns. It affects plants 'growth and survival and determines the nature of vegetation and wildlife habitat (Jennings *et al.*, 1999).

Table 3: Canopy covers classes

Classes	CC (%)	MCC (%)
1	0-5	2.5
2	5-25	15
3	25-50	37.5
4	50-75	62.5
5	75-95	85
6	95-100	97.5

Key: CC= canopy coverage; MCC= mean canopy coverage.

3.2.2 Species identification

All vascular plants were identified based on the knowledge acquired of the plant diversity from various field expeditions in Nyungwe National Park, Mukura-Gishwati forest reserves, the Volcanoes National Park in addition to the master thesis research on Pteridophytes of Albertine Rift and key Flora of Rwanda (Troupin,1982; Troupin, 1983; Troupin, 1978; Troupin, 1988; Troupin, 1985; Fischer & Killmann, 2008; Fischer *et al.*, 2010; Fischer & Killmann, 2008; Killmann & Fischer, 2005).

Photos of non-recognized plant species were taken for further identification using dichotomous keys by comparison of morphological characters states of specimens with species documented in the flora. Additionally, specimens were prepared for some unidentified plants and referred to the herbarium of the Royal Botanical Garden of Meise, Belgium for verifications and confirmation of those species.

3.2.3 Species life-forms

Raunkiaer's life-forms developed in Smith (1913) were used to characterize each species recorded. The idea behind their use is to investigate how plants in different conditions responded to changes as noted Du Rietz (1931), the plant-climate dependence is a condition for certain vegetation for the adaptation to survive unfavorable seasons and expressed by the statistical proportion between the life forms of all the species. Moreover, Raunkiaer in Du Rietz (1931) argued that changes in the flora due to human action never affected the proportions of life forms in its biological spectrum. In this study, the classification scheme of Raunkiaer's life-forms (1913) includes the following:

Table 4: Raunkiaer's life-forms used in the study

Life-forms	Symbols	Height (m)/other characteristics
- Megaphanerophytes	MGPH	>30
- Mesophanerophytes	MSPH	8-30
- Microphanerophytes	MPH	2 -8
- Nanophanerophytes	NPH	< 2
Chamaephytes	CH	Buds, shoot perennating on surface of the ground, < 25cm
Hemicryptophytes	H	dormant buds in the upper crust of the soil, herbs, rootstocks
Geophytes,	G	bulbs, rhizomes, tubers on stem, roots and root-buds
Helophytes & Hydrophytes	HH	semi-aquatic buds & perennating rhizomes or winter-buds
Therophytes	TH	Plants of favorable season that leave through unfavorable as seeds
Epiphytes and Stems succulents	E /S	stand a part themselves from the Phanerophytes

Raunkiaer in Smith (1913).

The life-form was revealed to be an expression of the interplay between a plant and its environment, a broad useful perceptive in classification that highlights different survival strategies of plants and their ecological relevance (Ewel & Bigelow, 1996).

3.2.4 Tree diameter at the breast height (DBH) measurement

The diameter at the breast height was deduced from the measure of circumference of trees as the relationship between the distance around the trunk at 1.30 m from the basis of the tree and its thickness that is translated to the geometrical relationship expressed in the following formula: $C = D\pi$ where, C= circumference; D= diameter and π = 3.1416. All trees with a DBH ≥2cm were measured using a diameter tape for the data set 1. A DBH meter has been used for the data set 2 and quiet similar data were obtained.

Huang *et al.* (2003) noted that the density and size distribution of trees is key for patterns of structure in rainforests and that diameter size and size distribution influences the tropical forest structure. In addition, the use of large DBH class should allow to consider cumulative effects of past anthropogenic over a 10-years period in tropical rainforests as argued by (Sabatier, 2001; Timilsina *et al.*, 2007). Moreover, when there is a high number of small DBH trees the forest is degraded and can be classified as secondary forest, whereas many trees with large DBH are characteristic of primary forests (Rödel & Ernst, 2004). In the present study, two larger individual tree species (DBH ≥2cm) were measured and the DBH averaged in plots surveyed. Trees with buttresses were measured at the point above the buttresses and the DBH averaged and reported. In accordance with the scale of Omeja *et al.*(2004), the following DBH and age classes as presented in table **5** has been used.

Table 5: Age and DBH classes

Age classes	DBH classes
Seedling	< 2
Sapling	2-9.9
Pole	10-19.9
Mature tree	> 20

Omeja *et al.* (2004)

3.2.5 Height measurement

It is established that differences in tree height classes of species in forest define different vertical patterns through the forest strata (Oliveira-Filho *et al.*, 1994). The tree height does not affect the estimates of canopy cover but canopy closure increases as the tree become taller (Jennings *et al.*, 1999). Height and diameter classes were found useful in assessment of changes due to human activities. A study has warned that regular height and diameter classes suggest that large scale disturbance by human hadn't occurred for long time as cited by Lorimer in Oliveira-Filho *et al.*, 1994). Another case study on second growth and old growth forest types observed that tree height varied significantly but there is not a significant interaction between forest type and diameter classes (Montgomery & Chazdon, 2001).

In this research, tree height was measured for the two tallest trees using an electronical tree height measuring device Vertex IV-36. It was calibrated twice a day to increase and optimize the measuring accuracy.

3.2.6 Level of disturbance

Biologists believe that species extinction mainly is associated to forest destruction. In a case study, different levels of disturbance have been identified to evaluate the impact of disturbance on biodiversity. Undisturbed, moderately and highly disturbed level of disturbance were identified (Alroy, 2017). Another study conducted in an Asian rainforest revealed that the understorey species of regenerating forest after 15 years since logging was similar to those of primary forest (Whitworth *et al.*, 2016). To evaluate the impact of human activities in Cyamudongo forest fragment and Nyungwe western main forest, three levels of disturbance were considered and signs of disturbance scored and recorded. Physiognomic types described were referred to disturbance level as follow: buffer zone (1) for changed habitat; secondary forest (2) for highly disturbed forest and primary forest (3) for moderately disturbed forest.

3.3 Global positioning System

A GPS was used to collect coordinates of different geographical locations (longitude, latitude and altitude) for further plotting of plant species distribution.

3.4 Data analysis

3.4.1 Taxa classification

The classification of taxa followed APG III (Angiosperm Phylogeny Group III) classification (Reveal & Chase, 2011 and the Syllabus of Plant Families: Bryophytes and seedless Vascular Plants (Frey *et al.*, 2009) with reference to the synopsis of classification of Lycophytina and Moniliformoses Kenrick & P.R. Crane to classify respectively angiosperms and Pteridophytes and the African Plant Database[1] and Kew plant of the World[2] used for verifications.

3.4.2 Diversity indices

Species richness, evenness, Shannon's diversity index (H') and Simpson's Index (λ) were calculated following the methods described in PAST Paleontological Statistics (Hammer *et al.*, 2009) and R 3.5.2 statistical program. Diversity measures were calculated separately for different community and the species richness was evaluated by the number of species per plot. Species were plotted in the Cartesian coordinates given by principal components (PCA) and the Principal Coordinates (PCoA) in order to identify groups basing on their similarity measure using PAST. All the regression analyses were performed using the statistical programs R 3.5.2 and PAST to examine the trends of different diversity among different diversity measures and the disturbance gradients. Group of species with similar traits were evaluated using the hierarchical agglomerative cluster analysis (McCune *et al.*, 2002). Hierarchical clustering method, Ward's method with Euclidian similarly measure non-constrained was used.

3.4.2.1 Species diversity

The plant species richness and diversity are simple and interpretable indicators of biological diversity (Malik & Nautiyal, 2016). For community description of the community, the common practice it is a common practice to use one of these indicators. The idea of a diversity index is to obtain a quantitative instrument of biological variability that allows to compare the living entities and their discrete components, in space or in time (Pielou, 1975). Diversity indices combine both richness and abundance. Alpha diversity (α), Beta diversity, Gamma diversity, Simpson's Index (λ), Shannon-Wiener Index (H') and Evenness were applied to evaluate the

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[1] https://www.ville-ge.ch/musinfo/bd/cjb/africa/recherche.php

[2] http://www.plantsoftheworldonline.org/

role of human in shaping the diversity of flora in Cyamudongo. Diversity is measured at different scales and thus it can be differentiated in alpha diversity, beta diversity and gamma diversity (Rachel, 2014). In this study, Gamma diversity (γ) is analyzed for Cyamudongo and Nyungwe, beta diversity measured between forests forest types whereas alpha diversity was evaluated as the species number per plots, transects or forest type.

Alpha diversity (α)

Also called community diversity, is the mean of species richness in the surveyed plots at Cyamudongo and Nyungwe western main block.

$\alpha = \frac{1}{n}\sum_{i=1}^{n} Si$, where Si represents the species richness in the plots and n, the number of plots.

Beta diversity (β)

Beta diversity was defined as differences in species composition among all surveyed plots at the site or the species turnover at landscape to regional scales and calculated by subtracting diversity from γ diversity:

$\beta = \gamma - \alpha$

Beta measure the heterogeneity in the data (McCune & Grace, 2002).

Gamma diversity (γ)

Gamma diversity, also called site diversity, is the species richness at Cyamudongo and the Nyungwe western block or the total regional species richness.

Shannon-Wiener Index (H')

$$H' = -\sum\left[\left(\frac{ni}{N}\right)\times \ln\left(\frac{ni}{N}\right)\right]$$

Where *ni*= number of individuals of each species (the i^{th} species) and N= total number of individuals for the site and *ln*= the natural logarithm of the number. Its values range from 0 to 5, but usually ranging from 1.5 to 3.5. This index is fairly sensitive to actual site differences and there are several instances where H' is similar between sites even though sites are different as it is a **measure of entropy** or **disorder** of the community according to Daly et *al*. (2018).

Simpson's Index (D)

Simpson's Index (D) is a measure of the dominance; therefore (1-D) measures the species diversity.

$$D = \frac{\sum n(n-1)}{N(N-1)}$$

Where *ni*= number of individuals of each species (the i^{th} species) and N= total number of individuals for the site with different annotations from literature. The Simpson index (D) was originally proposed by Simpson in Daly et *al*. (2018) and given by the following relationship:

$$H_{Si\,(P)}\,(D) = \sum_{i=1}^{s} P^2$$

But this was not found to be an intuitive measure of diversity since higher value suggests low diversity. The Simpson diversity index of the diversity (SDI) was proposed to measure the probability that two individuals randomly selected from a sample will belong to the same species (Z. A. Malik & Nautiyal, 2016) and in this study the formula, SDI=1-D was used to measure the diversity and its value ranges between 0 and 1. The greater value explains the greater sample diversity.

Evenness of species

Evenness expresses how evenly the individuals in the community are distributed over different species (Pielou, 1975). There is a partial correlation between the diversity and the evenness (Whittaker, 1972). Colwell (2009) defined evenness as a measure of the homogeneity of the abundance or species occurrence in a sample or a community. It was also termed as equitability of the species abundance distribution which is also a measure of the diversity (Daly *et al*., 2018). The equitability of the abundance of the species in Cyamudongo and the studied area of Nyungwe was calculated using the Pielou'evenness index as follow:

$$J' = {H'}/{H'\max} = H'/\log S$$

Where *H'*, is the number derived from the Shannon-Wiener Index and *H*'max, the maximum possible value of *H*'. Evenness indices are functions of some diversity measures and the number of individuals in a species sample. It ranges from 0 to 1 (Kvålseth, 2015).

3.4.2.2 Measure of similarity among community

Similarity indices indicate how close two samples are to another. Dissimilarity indices states "how apart" they are and indicate better the degree of resemblance between two ecological communities represented by the samples (Johnston, 1976). The similarity between two populations is expressed by Sorensen quotient that is denoted below as:

$$Qs=\frac{2c}{a+b}\times 100,$$

where, *a* is the number of the species in the population (A), b, the number of the species in the other population (B) and c is the number of species occurring in both populations. Values range from 0 to 1 whereas higher values suggesting greater similarity.

3.4.3 Ordination methods

Ordinal is in literal sense of arranging items along multiple axes as a means of generating hypotheses about underlying mechanisms and can also be used to test hypotheses when variables are correlating. In community ecology, ordination is very important to describe the strongest pattern in structuring species composition of the community (McCune & Grace, 2002) and underlying environmental gradients that influence patterns (Chahouki, 2012). According to Peet in Chahouki (2012), similar species or samples are plotted close to each other while dissimilar species or samples lie far apart from each other. In addition, McCune & Grace (2002) extended the idea and argued that species differences between two samples reflect their environmental differences including differences in biotic interactions and historical events in highly integrated fashion. The data matrix is subjected to a set of multivariate analyses to explore the plant community structure. To better interpret the analysis, it was assumed that infrequent species were noisy and sampled and were deleted for convenience reasons (McCune & Grace, 2002).The following ordination methods are used:

Principal components analysis (PCA)

The PCA is known to be earliest ordination technique for ecological data using rigid rotation to derive orthogonal axes to maximize the variance in the data set. A single analysis results in ordination of both species and samples. It is the basic Eigen analysis technique (Chahouki, 2012). It is the best known multidimensional scaling technique based on single value decomposition (Chahouki, 2012; McCune & Grace, 2002; Camiz *et a*l., 2017).

Eckart &Young in Camiz *et al.* (2017) theorems; have stated that the principal components are orthogonal directions, linear combinations of the original characters, along which the inertia (that is, the sum of squared distances of units to their centroid, in this case the scattering of relevés) is maximum. The mean and variance are basic concepts to compute PCA so that it may be applied only to quantitative (measure or frequency) data, but is currently accepted for presence/absence data, by giving sense to a weighted average between 0 and 1, which is actually a proportion of presences. In the present case, in order to perform this ordination method, data were required to normal distributed. The data has not to show significant trend, seasonality and other means on non-linearity. The reason why, they were forced to follow a normal distribution described by Gaussian distribution using PAST build in function before analysis. Data were first described by their Eigen values and corresponding percentages which allowed deciding orthogonal principal components and data plotted accordingly in Cartesian coordinates given by the Principal components. Groups were identified based on similarity using Euclidian similarity measure by default and the mean spanning was used to connect highly similar species/plots in space.

The Correspondence analysis (CA)

The correspondence analysis is method for geometrically modeling relationship between rows and columns of a matrix whose entities are categorical (Merz, 1999) and a multivariate graphical technique designed to explore relationship and examine associations among multiple variables (Eremina *et al.*, 2010). This method has an advantage that it produces two dual displays whose row and column have similar interpretations facilitating analysis and detection of relationship (Iordache *et al.*, 2012). The CA produces a map where each row and each column is represented by a point and contains three basics: a point in multidimensional space, a weight (mass) for each point and a distance function between the points, the chi-square (Greenacre, 2002).

Canonical Correspondence Analysis (CCA)

Problems in community ecology require to inferring species-environment relationship from community composition data and associated habitat measurement (Ter Braak, 1986). The CCA is a multivariate direct gradient analysis method that has become very widely used for this purpose. This method allows plotting individual species against a few environmental parameters to reveal the most important trends in data and observe the patterns. The CCA method is applied to examine how plant species compositions in Cyamudongo are associated with the measured environmental variables and the level of disturbance.

Principal coordinates analysis (PCoA)

Principal coordinates analysis also uses Eigen analysis and requires the normality assumption in order to test the variability of the chosen components. Data were described basing on the eigenvalues with their corresponding percentages. The first and the second Eigenvalues have given preferred coordinates since they showed that they were adequate to give full information in the data. The mean spanning tree used to connect highly similar species to form groups. This analysis was performed PAST.

3.4.3 Classification Analysis of flora diversity

In community ecology, a classification method put samples or community in groups and is computer assisted. The classifications of plants communities are based on their total floristic composition and recognized by their diagnostic species, as known differential and character species (Brown *et a*l., 2013). In an hierarchical classification, groups are nested within other groups in a divisive and an agglomerative way (Chahouki, 2012). The use of accepted quantitative methods in data collection allows a detailed information on species abundance and a description of the vegetation structure (Brown *et al.*, 2013). In this study, the hierarchical agglomerative cluster analysis is used to describe the vegetation structure in studied area stratified physiognomic and physiographic units, namely the buffer zone, secondary forest and primary forest.

The cluster analysis corresponds to the agglomerative classification with the objective to show graphically the relationship to cluster analyses and individual data points (Chahouki, 2012) and the neighbors joining clustering method with Manhattan similarity was applied to construct groups which are more similar to each other than to members of another group by their community composition (McCune & Grace, 2002). MVSP 3.2 software is used for analysis of the species abundance, main data matrix and UPGMA (Unweighted Pair Group Method with Arithmetic Mean) is performed resulting in UPGMA dendrogram where species are ordered according to their position on the dendrogram.

3.4.4 Statistical analyses

3.4.4.1 Correlation and regression analysis

All tree measurements will be submitted and environment variables will be submitted to Shapiro-Wilk test for the normality as a requirement to perform the correlation analysis (Gibson, 2002) that requires both the data sets to be normally distributed. In this case Pearson product moment correlation will be used to evidence that the two types of variables vary together. If data are found not normally distributed Spearman's rank correlation will be applied. In the other hand, the regression analysis will be used to test the dependence between variables as argued by Gibson (2002). SPSS software 3.2 will be used for the correlation and regression analysis of some tree metrics such as DBH, height, canopy cover and the disturbance level, altitude, habitat types and for correspondence analysis between life-forms and the type of forest under study.

3.4.4.2 Variation analysis of species occurrence in different forest types

The statistical difference in species that occurred in 2018, 2019, and 2020 considered as three response variables recorded in four vegetation types known as buffer zone, primary forest, secondary forest, and Gasumo forest has been evaluated. R software was used for MANOVA (Multiple Analysis of Variances), One-Way ANOVA and Two-Way ANOVA to test differences in means of species occurrences in 2018, 2019, and 2020.

MANOVA was first to explore the global difference at significance level alpha of 0.005 compared with the p-value computed from the data. Since the global p-value was equal to 2.595e-12, the null hypothesis was supported. Astonishingly, MANOVA didn't tell how the corresponding response behaved in the forest types. One-way ANOVA was applied for the identification of the specific dependent variable that contributed to the significant difference in each forest type was done but didn't say something about the influence of the cover percentage and the level of disturbance on these differences. In this context, two-way ANOVA intervened to identify the impact of these attributes on the species occurrences for the corresponding phases of data collection. During the analysis, R programming language was utilized while graphs that are presented was plotted with powerful R plotting tools plot 2 which is suitable to produce exemplary graphs easy to interpret. The analysis was performed species occurrences in 2018, 2019, and 2020, level of disturbance and cover percentage as attributes here abbreviated (HC: High cover, MiC: Middle cover, MoC: Moderate cover, LC: Low cover. HD: High Disturbed, CH: Changed the Habitant, MD: Moderate Disturbance).

3.4.5 Biological and Phyto-climate spectra analysis

According to Raunkiaer in Einar Du Rietz (1931), life-forms are the sum of a plant's adaptation to climate and the ratio of life-forms of different species in terms of number or percentage in a floristic community is the biological spectrum or life-form spectrum according to Milne& Milne in Thakur (2015) or the phyto-climatic spectrum (Smith, 1912). Differences in life-form distribution between the normal spectrum and the biological spectrum point out the life-form characterizing the phyto-climate or the vegetation under study as stated by Jyoti *et al*. (2014). The normal biological spectrum against which different life-form spectra are compared was earlier constructed by Raunkiaer according to Smith (1912). Proportions of life-forms for tropical rainforests respond to the Phanero-Therophytic phyto-climate where the normal biological spectrum estimates are Phanerophytes (46%), Chamaephytes (9%), Hemicryptophytes (26%), Cryptophytes (6%) and Therophytes (13%) (Smith, 1912; Raju *et al*., 2014; Thakur, 2015). This proposed normal spectrum serves as baseline to understand features in the study sites that are deduced by spectra comparison.

3.4.6 Chorological spectrum of phytogeographical districts (PDs)

With reference of publications of Brenan (1978), White (1983) & Adomou *et al*.(2006), the chorotype of each species were determined with the following main phytotochoria: GC: Guineo-Congolian regional center of endemism, Z: Zambesian regional center of endemism, S: Sudanian regional center of endemism, SZ: Sudano-Zambesian region, SG: Guineo-Congolian/Sudanian transition region i.e linking elements between the Guineo-Congolian and Sudanian Regions, and Wd: species with wide distribution like cosmopolitan, Pantropical and Paleotropical. Cosmopolitan (Cos) refers to species that occur in tropical and temperate region, Pantropical (Pan) region includes tropical Africa, America and Asia, while Paleotropical (Pal) refers to species distributed in tropical Africa, Asia with Madagascar and Australia. The proportions of various phytotochoria are calculated using the checklists of species obtained for each phytogeographical district defined with the help of the "Digital Flora of Central Africa"[3]

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[3] https://www.floredafriquecentrale.be/#/en/species/S561636

and Kew Plant of World Database[4] to evaluate the distribution of species in PDs. The observed phytogeographical patterns are described as a result of numerous ecological (geology, landform, soil and climate) and the historical processes such as climatic changes and anthropogenic activities as proven in a previous studies done by Adomou *et al.*(2006).

3.4.7 Spatial data analysis

3.4.7.1 Study sample mapping and analysis

The geographical coordinates of the study area have been plotted using Arc GIS.

3.4.7.2 Vegetation mapping

A satellite-derived vegetation index, the normalized difference vegetation index (NDVI) has been found to be useful as a predictor of the ground vegetation biomass (Borowik *et al.*, 2013). This index is based on the observation of distinct color's wavelengths of visible and near-infrared reflected by plants. The vegetation is dense containing some forest types in much more reflected radiations in near-infrared wavelengths than in visible and the vegetation is sparse consisting of grassland, tundra or desert with small difference between visible and near-infrared wavelengths reflected and according to the Nasa Earth Observatory (2000), the NDVI is calculated as follows:

NDVI = (NIR — VIS)/ (NIR + VIS)

Borowik *et al.* (2013) studying the relationship between NVDI and the ground vegetation biomass and have confirmed the seasonal shapes of the relationship. The NDVI were also found to be a good instrument for the identification of areas that experienced the vegetation loss due to human activities in Somalia by a statistical modeling method which eliminated the relationship between rainfall and vegetation (Omuto *et al.*, 2010). This remote sensing modeling approach allows NDVI calculations which result in a number ranging from -1 to +1. No green color results in a value close to zero (no vegetation) and the highest possible density of green leaves corresponds to a value of close to +1 (0.8 - 0.9) (Nasa Earth Observatory, 2000). The vegetation maps of the Cyamudongo and the study area of Nyungwe were obtained from NDVI satellite images. The vegetation of Cyamudongo and the studied area of Gasumo were classified using NDVI values according table 6 as presented below as proposed by Zaitunah *et al.* (2018).

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[4] http://www.plantsoftheworldonline.org/

Table 6: NDVI vegetation classes

Classes	NDVI Values	Vegetation classes
I	0-0,15	Lowest dense
II	0,15-0,3	lower dense
III	0,3-0,45	Dense
IV	0,45-0,6	Higher dense
V	> 0,6	Highest dense

CHAPTER 4. RESULTS

4.1 Evolution of the Vegetation state of Cyamudongo and Nyungwe at Gasumo study area

4.1.1 NDVI classes and corresponding and surface area

The Normalized Difference Vegetation Index (NDVI) values remotely sensed from satellites for 2016, 2018, 2019 and 2020 are respectively described in five vegetation classes presented at table 7, 8, 9 and 10.

Table 7: NDVI values and corresponding surface area in Sqm of 2016

Classes	NDVI Values	area in Sqm
I	0.134-0.24	427639,357
II	0.24 - 0.29	1381989,516
III	0.29- 0.33	2183999,506
IV	0.33- 0.37	2501309,261
V	0.37 - 0.47	1405543,785

Table 8: NDVI values and corresponding surface area in Sqm of 2018

Classes	NDVI Values	area in Sqm
I	0.09- 0.23	309188,9483
II	0.23- 0.31	1208621,177
III	0.31- 0.36	2039720,476
IV	0.36- 0.41	2721423,018
V	0.41- 0.52	1621240,672

Table 9: NDVI values and corresponding surface area in Sqm of 2019

Classes	NDVI Values	area in Sqm
I	0.15- 0.22	294793,4355
II	0.22- 0.27	1171825,019
III	0.27- 0.30	2059759,449
IV	0.30- 0.33	2708840,645
V	0.33- 0.40	1663458,685

Table 10: NDVI values and corresponding surface area in Sqm of 2020

Classes	NDVI Values	area in Sqm
I	0.10-0.22	312120,8114
II	0.22-0.28	1194404,33
III	0.28-0.33	2172046,552
IV	0.33-0.37	2633022,185
V	0.37-0.51	1745572,297

The NDVI values in four periods of data collection changed as exposed in table 7, 8, 9 and 10 for both the low and upper limits of NDVI values and the corresponding area of vegetation classes. NDVI values decreased from 2016 to 2018 for the lower limits of the first two classes with sparse vegetation while the corresponding surface areas decreased with the vegetation classes I, II. In addition, the NDVI values increased in moderate dense vegetation and higher dense vegetation in classes, III, IV and V with an increase in in the surface area covered accordingly. These values symbolize a reduced level of disturbance between 2016 and 2018 and, an increase of the vegetation cover. Meanwhile, the situation reversed in 2019 where NDVI values decreased for the low and upper values compared to the year 2018. This decrease implies a decrease in vegetation cover. More interestingly in 2020, the NDVI values for the higher dense vegetation increased as well as the surface covered by the vegetation. Figure 12 presents NDVI classes mean values for the study periods and shows that for 2018, the NDVI values were higher than those of 2016, 2019 and 2020 for the four vegetation classes except for the first one.

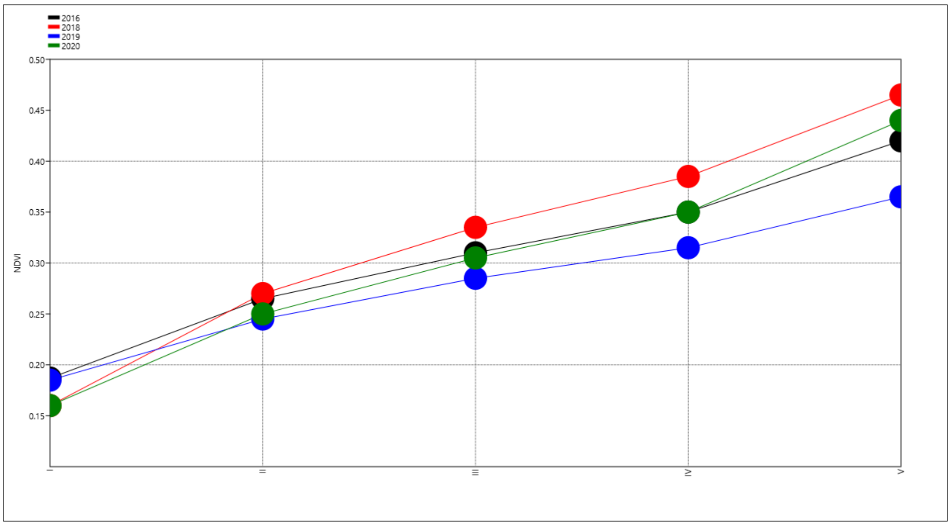


Figure 12: Dynamic of NDVI in 2016, 2018, 2019, 2020

In general, the NDVI in Cyamudongo and Nyungwe, the study of Gasumo ranging between 0.1 and 0.5 allow qualifying the vegetation as dense with different levels of disturbance with five classes.

4.1.2 Trends of forest cover changes and landscape dynamics before and during the study period

The land cover classification results of the study area varied among study periods as presented at figure 13.

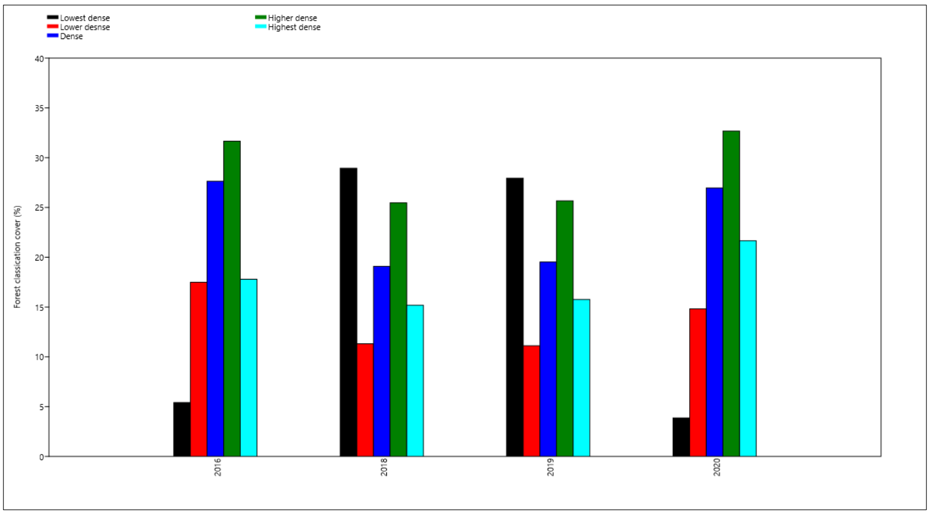


Figure 13: Spatial distribution of land cover classes in 2016, 2018, 2019, 2019

Figure 10 showed almost similar trends in forest cover between 2018 and 2019 dominated by lower dense vegetation class while 2016 and 2020 were dominated by higher dense vegetation. During the study period, the vegetation maps are presented from Fig 14 to 17 respectively for the period before the study (2016) and the following years 2018, 2019, 2020. The lowest vegetation density was found in areas surrounding the park in buffer zones, mostly at Mataba (South-West) and the center directed to the north of Cyamudongo. The patches and the north east of the studied area of Gasumo are mostly dominated by the lowest dense vegetation. In terms of increase of the surface areas for different vegetation classes, patterns are presented in table 11.

Table 11: Increase and decrease of land cover period 2016-2020

Vegetation class	area in sqm		area in sqm			area in sqm			area in sqm		Rate (sqm/yr)
	2016	2018	increase	Decrease	2019	increase	Decrease	2020	increase	Decrease	
Lowest dense	427639,357	309189		-118450,4	294793,44		-14396	312120,8	17327,4		3465,5
Lower dense	1381989,52	1208621		-173368,3	1171825		-36796	1194404,3	22579,3		4515,9
Dense	2183999,51	2039720		-144279,0	2059759,4	20039		2172046,6	112287,1		22457,4
Higher dense	2501309,26	2721423	220113,8		2708840,6		-12582	2633022,2		-75818,5	-15163,7
Highest dense	1405543,78	1621241	215696,9		1663458,7	42218		1745572,3	82113,6		16422,7

NDVI range of land cover types (Table 7, 8, 9, 10) as well as their corresponding surface area from 2016 to 2020 indicated changes. The degradation reduced in lower land cover where the initial surface covered decreased until 2019 and higher dense land cover increased with increase in greenness in 2020. From figure 14-17, the extent of the variation of vegetation cover and changes are exposed on maps.

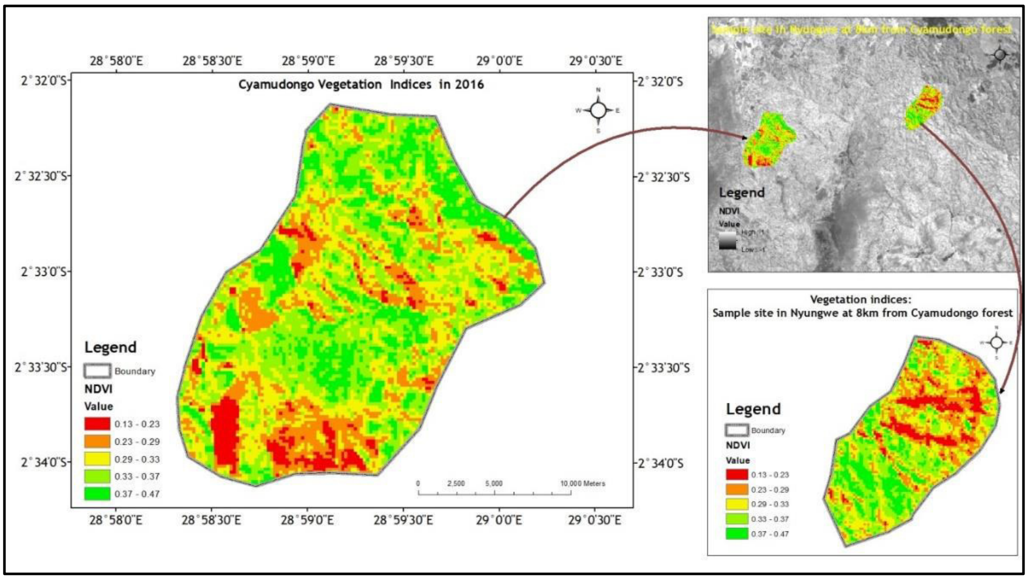


Figure 14: Map showing the vegetation density in 2016

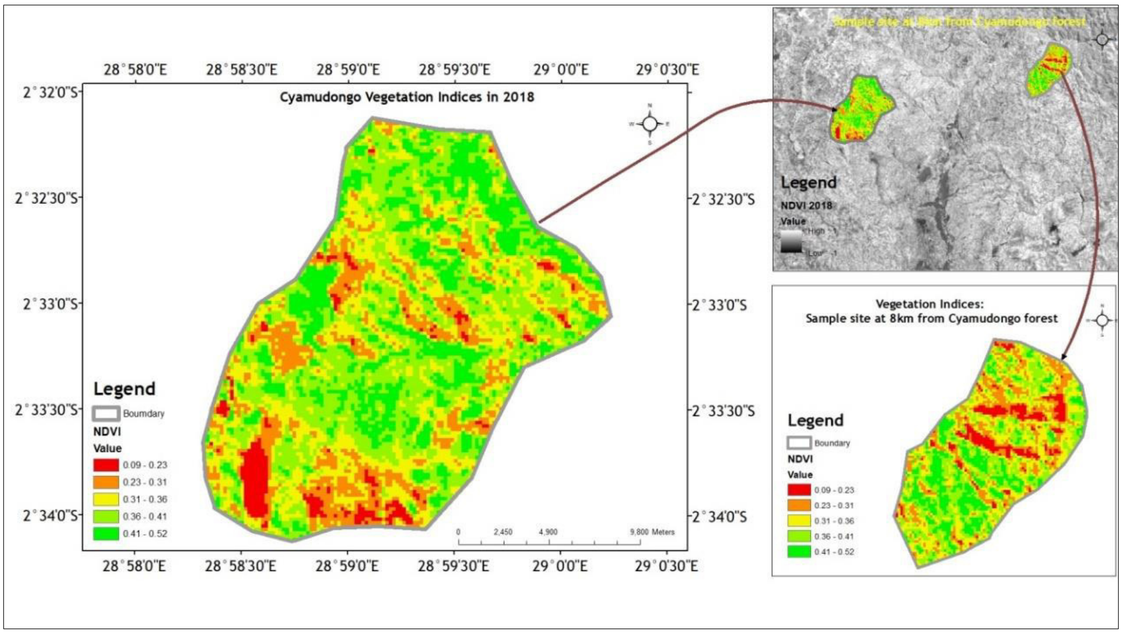


Figure 15: Map showing the vegetation density in 2018

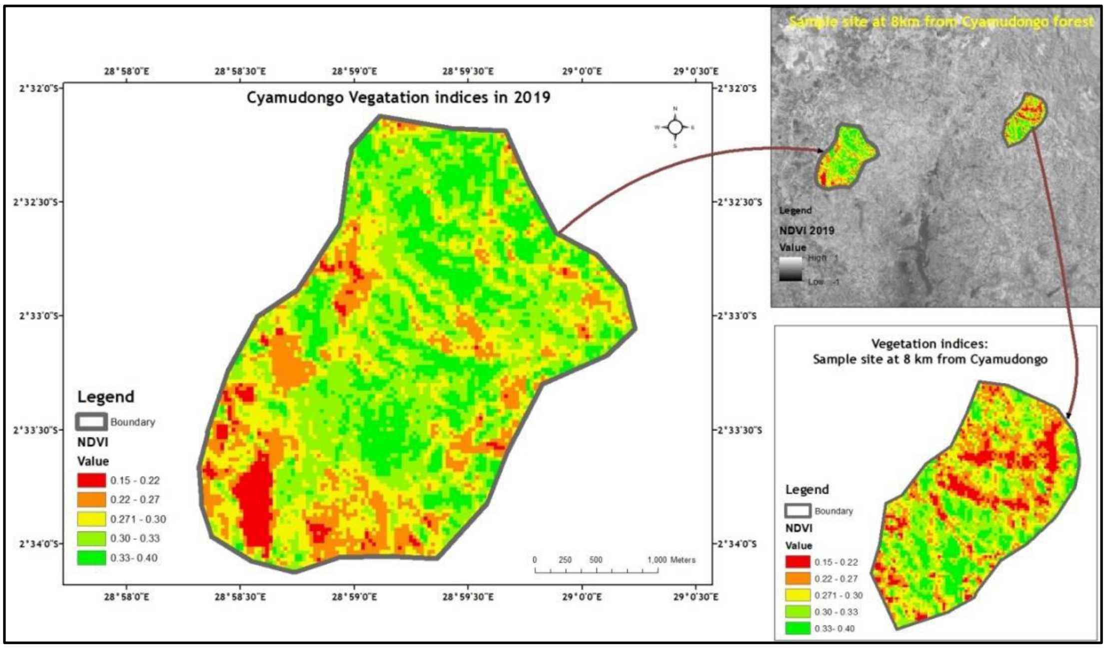


Figure 16: Map showing the vegetation density in 2019

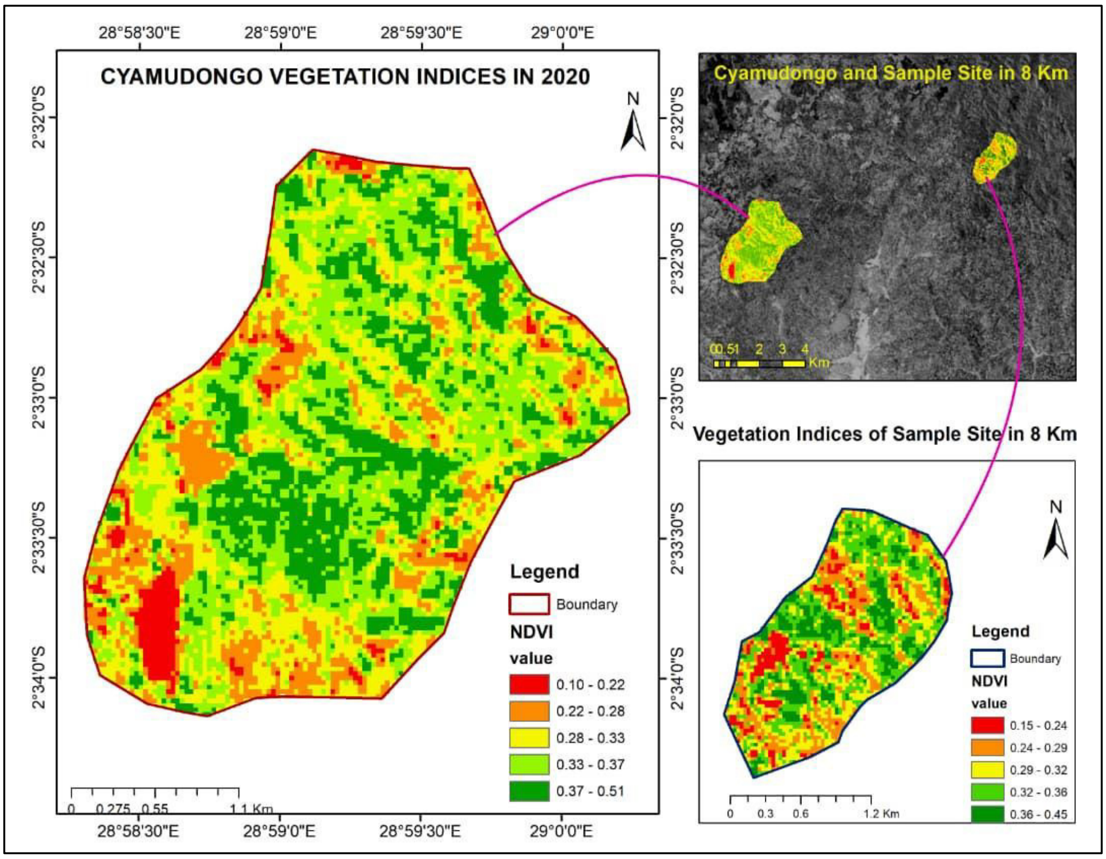


Figure 17: Map showing the vegetation density in 2020

The study showed that the forest coverage and the forest density increased from 2016-2020. Furthermore, areas surrounding Cyamudongo and closest to local communities and mostly made of buffer zones and secondary forest patches are likely to be disturbed by human activities and the existence of infrastructure (roads) crossing the forest. The inner part of the forest with primary forest patches show the highest forest coverage with NDVI higher than other land cover indicated by the highest crown density. Gasumo couldn't escape the high level of disturbance given the lower levels of land cover with lower NDVI dominating in the study area.

4.2 Description of the study area

The study covered an area of 13 500 m^2 distributed among 60 transects and 15 plots with 12000 m^2 and 1500 m^2 respectively. Figure 18 below shows how samples were distributed according to the altitudinal range of the four types of physiognomic unities.

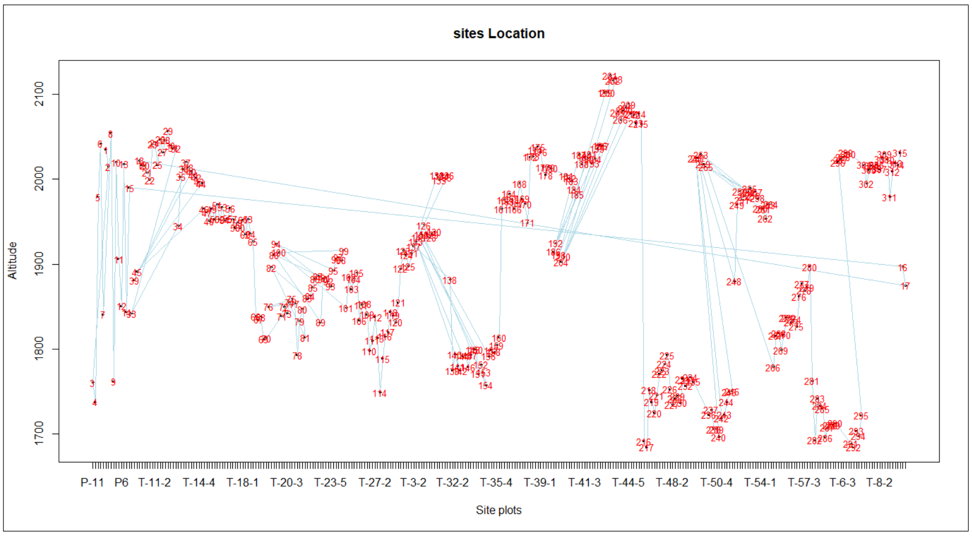


Figure 18: Plots distribution according to the altitudinal gradient

This graph shows how the sample plots and transects considered were distributed significantly considering different altitudinal ranges in Cyamudongo and Gasumo. Transects have been chosen with a considerable distance among themselves.

4.3 Floristic composition

The total record of the three phases of the study has been 32, 617 of vascular plants including Spermatophyta and Pteridophyta plant species. In total, the diversity of vascular plants species recognized at Cyamudongo and Gasumo study area of rainforests was estimated at to 494 species distributed oddly in different sites and study periods according to table 12 and among, which 43, 54 % where found to be shared by Cyamudongo as well as by the closest study are of Nyungwe. Considering all physiognomic communities, Cyamudongo alone was found to hold the highest species diversity alone with 48.54 % while 7.92 % were only confined to Gasumo.

Table 12: Species occurrence level in forest types according to study phases

	Spermatophyta			**Pteridophyta**		
FT/ Study phases	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
BZ	54,0	46,4	40,3	4,0	5,5	4,7
SF	66,4	53,6	62,6	9,3	9,3	8,1
PF	52,8	44,3	43,9	6,1	7,7	6,7
GS	56,7	50,2	50,2	8,9	8,3	8,7

Table 12 shows that the occurrence of Spermatophyta was the lowest in primary forest and the highest in the secondary forest followed by Gasumo study area as for the occurrence of Pteridophyta species, nevertheless with the lowest occurrence in the buffer zone. In addition, the increase in number of flowering plants dominated by Angiosperms correlate positively with the occurrence of non-flowering vascular plants (Pteridophyta).

From the record, 82.2% were identified at the species level, 95.2% to genus level, and 98.2% at family level. The remaining 1.8% couldn't be assigned to any taxonomic rank due the absence of flowers during the period of the study. The table 13 gives a general figure of taxa distribution according to their ranks of orders, families and species.

Table 13: Distribution of taxa according to ranks

	Spermatophytes (%)		**Pteridophytes (%)**	**Total (%)**
	Gymnosperms	Angiosperms		
Orders	1 (2,6)	31 (79,5)	7 (19,9)	39 (100)
Families	2 (1,9)	90 (84,9)	14 (13,2)	106 (100)
Species	2 (0,4)	427 (86,4)	65 (13,2)	494 (100)

Consequently, the total numbers of taxa recognized in three phases of research belonged to 106 families with a high level of occurrence of Angiosperms for orders and more for families and species. It was found that 62 of families were represented by less than 4 species and 33 were monospecific and a summary of poorest families is presented at the table 14.

Table 14: Species-poorest families

Monospecific	2 species	3 species
Hernandiaceae	Araceae	Lauraceae
Monimiaceae	Dioscoreaceae	Hypericaceae
Colchicaceae	Cyperaceae	Phyllanthaceae
Smilacaceae	Zingiberaceae	Cannabaceae
Amaryllidaceae	Crassulaceae	Rosaceae
Proteaceae	Oxalidaceae	Myrtaceae
Malpighiaceae	Achariaceae	Anacardiaceae
Putranjivaceae	Chrysobalanaceae	Loganiaceae
Rhizophoraceae	Clusiaceae	Araliaceae
Combretaceae	Rhamnaceae	Polypodiaceae
Thymeleaceae	Melianthaceae	
Balanophoraceae	Capparaceae	
Strombosiaceae	Loranthaceae	
Basellaceae	Polygonaceae	
Cactaceae	Campanulaceae	
Caryophyllaceae	Apiaceae	
Phytolaccaceae	Lycopodiaceae	
Cornaceae	Selaginellaceae	
Ebenaceae	Thelypteridaceae	
Sladeniaceae		
Boraginaceae		
Scrophyllariaceae		
Convolvulaceae		
Aquifoliaceae		
Cardiopteridaceae		
Pittosporaceae		
Pinaceae		
Podocarpaceae		
Marattiaceae		
Gleicheniaceae		
Cyatheaceae		
Tectariaceae		

Meanwhile, some families were found to be more diversified with more than 10 species as presented at fig.19.

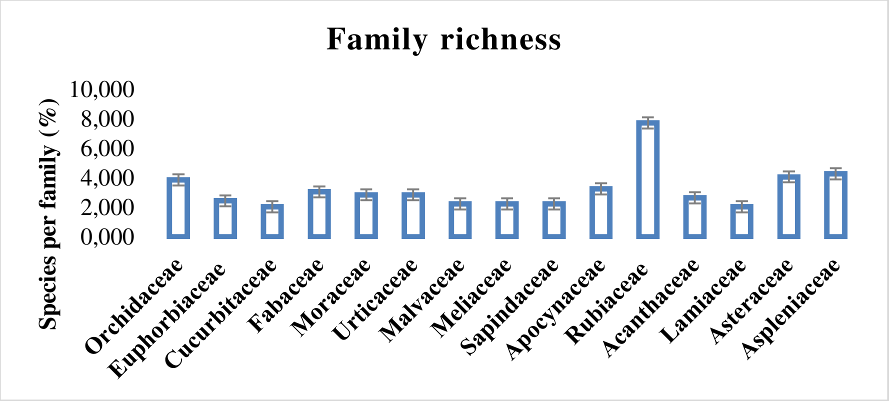


Figure 19: The richest vascular plant families

All taxa identified to species level are listed in the appendix 1. Figure 14 shows that vascular plant families were dominated respectively by families of Rubiaceae, Aspleniaceae, Asteraceae, Orchidaceae, Apocynaceae, Fabaceae, Urticaceae, Moraceae, Acanthaceae, Euphorbiaceae, Sapindaceae, Meliaceae, Malvaceae. Species inventory was by far dominated by angiosperms which accounted for 86.4% of all species. Pteridophytes represented 13.2 % of the species and Gymnosperms represented by only two species (0.4%) with Pinus patula Schltdl. & Cham., introduced in the buffer zones and *Podocarpus milanjianus* occurring in natural forests.

Table 15: Taxonomic list of the total vascular plants of the study areas

		Division	Tracheophyta			
Subdivision	**Class**	**Orders**	**Families**	**Species**	**LF**	**Phytochoria**
Lycophytina	**Lycopsida**	**Lycopodiales**	**Lycopodiaceae**	*Huperzia mildraedii* (Herter) Pic. Serm.	E	GC
				Lycopodium clavatum L.	CH	Cos
		Selaginellales	**Selaginellaceae**	*Selaginella kraussiana* (Kunze) A. Braun	H	Cos
				Selaginella lewalleana Bizzarri	H	End (RA)
Euphyllophytina	**Marratiopsida**	**Marattiales**	**Marattiaceae**	*Marattia fraxinea* Sm.	CH	SE. & S. Brazil.
(Moniliformopses)	**Polypodiopsida**	**Hymenophyllales**	**Hymenophyllaceae**	*Hymenophyllum kuhnii* C. Chr.	E	A-trp
				Hymenophyllum sp	E	A-trp
				Hymenophyllum sp2	E	A-trp
				Tr*ichomanes borbonicum* Bosch	E	PAN
				Trichomanes mannii Hook.	E	A-trp
				Trichomanes melanotrichum Schltdl.	E	A-trp-UZ-M
				Trichomanes sp1	E	A-trp
				Trichomanes sp2	E	A-trp
		Gleicheniales	**Gleicheniaceae**	*Dicranopteris linearis* (Burm. f.) Underw.	CH	Pal
		Cyatheales	**Cyatheaceae**	*Cyathea manniana* Hook.	Ph	A-trp
		Polypodiales	**Dennstaediaceae**	*Blotiella bouxiniana* Pic.Serm.	HE	End (RA)
				Blotiella glabra (Bory) R. M. Tryon	He	A-trp-UZ-M
				Histiopteris incisa (Thunb.) J. Sm.	He	Pan
				Pteridium aquilinum (L.) Kuhn	He	Cos
			Pteridaceae	*Antrophyum mannianum* Hook.	E	A-trp
				Coniogramme africana Hieron.	He	A-trp
				Pellaea doniana Hook.	He	A-trp
				Pteris auquieri Pic. Serm.	He	Mo(EA)
				Pteris catoptera Kunze	He	GC-UZ
				Pteris dentata Forssk.	He	GC-Z-SAR-UZ-M
				Pteris pteridioides (Hook.) Ballard	He	A-trp-M

	Vittaria guineensis Desv.	E	GC
	Vittaria reekmansii Pichi Serm.	E	GC-Z
Aspleniaceae	*Asplenium aethiopicum* (Burm. f.) Bech.	E,Ge	Pal
	Asplenium anisophyllum Kunze	He	A-trp-UZ-M
	Asplenium bugoiense Hieron.	He, Ge	Mo(EA)
	*Asplenium cei*i Pic. Serm.	E	A-O-Z
	Asplenium dregeanum Kunze	E	A-trp-UZ-M
	Asplenium elliottii C. H. Wright	E,Ge	Mo(EA)
	Asplenium erectum Bory ex Willd.	He	A-trp-O-UZ-M
	Asplenium friesiorum C. Chr.	He	A-trp-O-UZ-M
	Asplenium gemmascens Alson	He	GC-Z
	Asplenium gemmiferum Schrad.	He	GC-Z-UZ-KN-CP
	Asplenium linkii Kuhn	E, Ge	Mo(EA)
	Asplenium mannii Hook.	E	A-trp-O-UZ-M
	Asplenium megalura Hieron.	E	A-trp-O-UZ
	Asplenium mildbraedii Hieron.	E, Ge	Mo(EA)
	Asplenium obscurum	HE	Z-UZ-M-trp ASIA
	Asplenium protensum Schrad.	He, Ge	Afr-trp-Z-UZ-KN-CP-M
	Asplenium rukararense Hieron.	E, Ge	End (RA)
	Asplenium sandersonii Hook.	E, Ge	A-trp-O-UZ-M
	Asplenium sp1	E	A-trp
	Asplenium sp2	E	A-trp
	Asplenium unilaterale C. Chr.	He	Afr-trp-Z-UZ
Thelypteridaceae	*Christella dentata* (Forssk.) Brownsey & Jermy	He	Cos
	Pseudocyclosorus pulcher (Bory ex Willd.) Holttum	He	A-trp-SAR-M
Dryopteridaceae	*Didymochlaena truncatula* (Sw.) J. Sm.	CH	Pan
	Dryopteris dentata (Forssk.) C. Chr.	He	Pan

				Dryopteris kilimensis (Kuhn) Kuntze	He	Mo(A-trp)
				Dryopteris manniana (Hook.) C. Chr.	He	GC-EA
				Dryopteris pentheri (Krasser) C. Chr.	He	A-trp-O-KN-CP-UZ-M
				Polystichum transvaalense N. C. Anthony	He	A-trp-O-UZ-CAP-M
			Tectariaceae	*Tectaria gemmifera* (Fée) Alston	He	A-trp-O-UZ
			Oleandraceae	*Arthropteris anniana* Lawalrée	E, Ge	A-trp-M
				Arthropteris orientalis (J. F. Gmel.) Posth.	E, Ge	A-trp-O-Yem-M
				Nephrolepis undulata (Afzel. ex Sw.) J. Sm.	He	Pas
				Oleandra distenta Kunze	He	A-trp-O-UZ-CAP-M
			Polypodiaceae	*Drynaria volkensii* Hieron.	E	A-trp
				Loxogramme abyssinica (Baker) M. G. Price	E	A-trp-KN-M
				Pleopeltis excavata (Bory ex Willd.) Sledge	E	A-trp-O-UZ-M
Spermatophyta	**Magnoliids**	**Piperales**	**Piperaceae**	*Peperomia fernandopoiana* C. DC.	E&G	A-trp
				Peperomia tetraphylla (G. Forst.) Hook. & Arn.	E	A-trp-Z
				Piper capense L. f.	CH	A-trp-Z-M
				Piper guineense Schumach. & Thonn.	PH (L)	A-trp-M
				Piper umbellatum L.	CH	Pan
		Laurales	**Hernandiaceae**	*Illigera pentaphylla* Welw.	PH (L)	GC- Mo(EA)
			Lauraceae	*Beilschmiedia rwandensis* R. Wilczek	PH	Mo (EA)
				Ocotea usambarensis Engl.	PH	Mo (EA-SA)
				Persea americana Mill.	PH	Pan
			Monimiaceae	*Xymalos monospora* (Harv.) Baill.	PH	A-trp
		Magnoliales	**Annonaceae**	*Annona ferruginea* (R.E.Fr.) H.Rainer.	PH (L)	Mo (EA)
				Annona senegalensis Pers.	PH (L)	A-M
				Apodytes sp	PH	Mo (A-M)
				Artabotrys sp.	PH (L)	Pal
				Monanthotaxis orophila (Boutique) Verdc.	PH (L)	GC
				Uvaria angolensis Welw. ex Oliv.	PH (L)	GC-Afro-Z
	Monocots	**Alismatales**	**Araceae**	*Arisaema mildbraedii* Engl.	G	A-trp

		Culcasia scandens auct.	PH (L)	SZ
Dioscoreales	**Dioscoreaceae**	*Dioscorea sp 1*	G (L)	COS
		Dioscorea sp2	G (L)	COS
Liliales	**Colchicaceae**	*Gloriosa superba* L.	G	A-trp
	Smilacaceae	*Smilax anceps* Willd.	PH (L)	A-trp-SAR-UZ
Asparagales	**Amaryllidaceae**	*Scadoxus multiflorus* (Martyn) Raf.	G	A-trp-O-SAR
	Asparagaceae	*Asparagus asparagoides* (L.) Druce	TH	Mo(EA-SA)
		Chlorophytum sp	G	Pan
		Chlorophytum comosum (Thunb.) Jacques	G	GC-Afro-UZ
		Chlorophytum sparsiflorum Baker	G	A-trp
		Dracaena fragrans (L.) Ker Gawl.	PH	A-trp
		Dracaena laxissima Engl.	PH	SZ-Z
		Dracaena steudneri Engl.	PH	GC-Afro-Z
	Orchidaceae	*Angraecum sp*	E	GC-SZ-Afro-UZ-M
		Calanthe sylvatica (Thouars) Lindl.	H	A-trp
		Diaphananthe rohrii (Rchb. f.) Summerh.	H	A-trp
		Disperis reichenbachiana Welw. ex Rchb. f.	H	A-trp
		Disperis reklieberae Eb. Fisch., Killmann & al.	H	A-O
		Eulophia galeoloides Kraenzl.	H	A-trp
		Hetaeria heterosepala (Rchb. f.) Summerh.	H	A-trp-M
		Eulophia streptopetala Lindl.	H	A-trp
		Liparis bowkeri Harv.	H	Mo (EA-SA)
		Orchidaceae sp 1	E	A-trp
		Orchidaceae sp 2	E	A-trp
		Orchidaceae sp 3	E	A-trp
		Polystachya bifida Lindl.	E	GC
		Polystachya kermesina Kraenzl.	E	GC
		Polystachya simplex Rendle	E	GC-Afro-Z
		Polystachya sp1	E	A-trp
		Polystachya sp2	E	A-trp
		Rhipidoglossum delepierreanum (J.-P. Lebel & Geerinck) Eb. Fisch., Killmann & al.	E	GC

			Tridactyle eggelingii Summerh.	E	GC
Commelinids	**Commelinales**	**Commelinaceae**	*Commelina benghalensis* L.	H	Pan
			Commelina capitata Benth.	H	A-trp
			Commelina diffusa Burm. f.	H	A-trp
			Palisota mannii C.B. Clarke	H	GC-Afro
	Poales	**Cyperaceae**	*Mariscus longibracteatus* Cherm.	G	A-trp-UZ
			Mariscus sumatrensis (Retz.) J. Raynal	G	A-trp-UZ
		Poaceae	*Isachne mauritiana* Kunth	TH	A-trp
			Leersia hexandra auct.	TH	A-trp
			Oplismenus hirtellus (L.) P. Beauv.	TH	A-trp
			Panicum heterostachyum Hack.	TH	GC-Z
			Setaria megaphylla (Steud.) T. Durand & Schinz	TH	A-Trp-SAR-UZ
	Zingiberales	**Zingiberaceae**	*Aframomum sp*	G	A-trp-M
			Renealmia orophila Dhetchuvi & E. Fisch.	G	GC
Eudicots	**Ranunculales**	**Menispermaceae**	*Cissampelos mucronata* A. Rich.	PH (L)	A-trp-UZ
			Stephania abyssinica (Quart. -Dill. & A. Rich.) Walp.	PH (L)	A-trp-UZ
			Stephania cyanantha Welw. ex Hiern	PH (L)	GC-SZ-Afro-Z
			Tiliacora funifera (Miers) Oliv.	PH (L)	A-trp-UZ
			Tinospora caffra (Miers) Troupin	PH (L)	GC-Afro-Z
			Tinospora orophila Troupin	PH (L)	GC
		Ranunculaceae	*Clematis grandiflora* DC.	PH (L)	GC-SZ
			Clematis hirsuta Guill. & Perr.	PH (L)	SZ-GC-SA
			Clematis sinensis Lour.	PH (L)	MO (A-trp)
			Thalictrum rhynchocarpum Quart. -Dill. & A. Rich. ex A. Rich.	TH	GC-Afro-Z
	Protelales	**Proteaceae**	*Grevillea robusta* A. Cunn. ex R. Br.	PH	Pal
Core Eudicots	**Saxifragales**	**Crassulaceae**	*Crassula gravinkii* Mildbr.	H	GC-Afro
			Kalanchoe integrifolia Baker	PH	M
		Connaraceae	*Agelaea macrophylla*	PH (L)	GC
			Agelaea mildbraedii	PH (L)	GC
			Jaundea pinnata (P. Beauv.) G. Schellenb.	PH (L)	GC-SZ
			Rourea sp	PH (L)	A-trp

Oxalidaceae	*Biophytum helenae* Buscal. & Muschl.	H	GC-Z
	Oxalis latifolia Kunth	H	Pan
Vitaceae	*Cayratia clematidea* (F.Muell) Domin.	PH (L)	
	Cissus oliveriana (Engl.) Gilg	PH (L)	GC
	Cissus petiolata Hook. f.	PH (L)	A-trp
	Cissus rubiginosa (Welw. ex Baker) Planch.	PH (L)	A-trp
	Cyphostemma bambuseti (Gilg & M. Brandt) Desc. ex Wild & R. B. Drumm.	PH (L)	GC-Afro-Z
	Cyphostemma kilimandscharicum (Gilg) Desc. ex Wild & R. B. Drumm.	PH (L)	GC-Afro-Z
	Leea guineensis G. Don	PH (L)	PAN
Achariaceae	*Lindackeria kivuensis* Bamps	MGPH	GC-Afro-Z
	Lindackeria sp	MGPH	GC-Afro-Z
Chrysobalanaceae	*Magnistipula butayei* De Wild.	MGPH	A-trp
	Parinari excelsa Sabine	MGPH	Pan
Clusiaceae	*Garcinia volkensii* Engl.	MGPH	??
	Symphonia globulifera L. f.	MGPH	GC-Afro
Euphorbiaceae	*Acalypha neptunica* Müll. Arg.	CH	A-trp
	Acalypha psilostachya	CH	GC-Afro-Z
	Acalypha racemosa Wall. ex Baill.	CH	A-trp-SAR
	Acalypha sp	CH	A-trp
	Alchornea hirtella Benth.	PH	A-trp-UZ
	Croton macrostachyus Hochst. ex Delile	MGPH	A-trp
	Croton megalocarpus Hutch.	MGPH	A-O-Z
	Erythrococca fischeri Pax	MIPH	MO(EA)
	Macaranga kilimandscharica Pax	MGPH	A-O-Z
	Neoboutonia macrocalyx Pax	MGPH	GC-Z
	Sapium ellipticum (Hochst.) Pax	MGPH	A-trp-UZ
	Tragia brevipes Pax	PH (L)	GC-Z
Hypericaceae	*Harungana madagascariensis* auct.	NPH	A-trp-UZ-Ind
	Harungana montana Spirlet	MSPH	GC
	Hypericum peplidifolium A. Rich.	H	SZ-Z
Malpighiaceae	*Flabellaria sp*	PH (L)	A-trp
Ochnaceae	*Campylospermum sp*	PH	PAL

			Ochna holstii Engl.	MIPH	GC-Afro-Z
			Ochna sp	MSPH	GC-Afro-Z
			Ouratea densiflora De Wild. & T. Durand	MIPH	GC-Afro-Z
		Passifloraceae	*Adenia bequaertii* Robyns & Lawalrée	PH (L)	GC-Afro
			Adenia lewallei A. Robyns	PH (L)	GC
			Adenia sp	PH (L)	GC
			Passiflora edulis Sims	PH (L)	Pan
		Phyllanthaceae	*Bridelia brideliIfolia* (Pax) Fedde	PH	SZ
			*Phyllanthus nummulariifoliu*s Poir.	PH (L)	A-trp
			Phyllanthus odontadenius Müll. Arg.	PH (L)	A-trp
		Putranjivaceae	*Drypetes gerrardii* Hutch.	MGPH	SZ
		Rhizophoraceae	*Cassipourea ruwensorensis* (Engl.) Alston	PH	GC-Afro
		Salicaceae	*Casearia runssorica* Gilg	MSPH	SZ-Afro
			Dovyalis macrocalyx (Oliv.) Warb.	MSPH	SZ
			Dovyalis spinosissima auct.	MIPH	Z
			Oncoba spinosa Forssk.	MSPH	A-Trp-SAR-UZ
		Violaceae	*Rinorea angustifolia* (Thouars) Baill.	MIPH	M
			Rinorea brachypetala (Turcz.) Kuntze	MIPH	A-trp
			Rinorea gracilipes Engl.	MIPH	GC-Afro
			Rinorea sp	MSPH	A-trp
Rosids	**Celastrales**	**Celastraceae**	*Elaeodendron buchananii* (Loes.) Loes.	MGPH	A-trp
Fabids			*Hippocratea africana* Willd. Loes.	PH (L)	SZ-Afro-UZ-M
			Hippocratea apocynoides Welw. ex Oliv.	PH (L)	GC-Z
			Hippocratea parvifolia Oliv.	PH (L)	A-trp
			Maytenus undata (Thunb.) Blakelock	MIPH	A-trp-UZ-Cm
			Pristimera sp	PH	Pal
			Salacia erecta (G. Don) Walp.	PH (L)	A-trp
			Salacia oblongifolia Oliv.	PH (L)	GC
			Salacia sp	PH (L)	GC
	Cucurbitales	**Begoniaceae**	*Begonia ampla* Hook. f.	E	GC
			Begonia haullevilleana De Wild.	E	SZ
			Begonia meyeri-johannis auct.	PH (L)	A-M

		Begonia oxyloba Welw. ex Hook. f.	E	A-trp-M
		Begonia pulcherrima Sosef	H	GC
		Begonia sp	E	A-trp
	Cucurbitaceae	*Coccinia mildbraedii* Harms	PH (L)	GC-Z
		Coccinia sp	PH (L)	A-trp
		Lagenaria sphaerica (Sond.) Naudin	PH (L)	A-O-UZ- Cm
		Momordica cissoides Benth.	PH (L)	A-trp
		Momordica foetida Schumach.	PH (L)	A-trp-UZ
		Momordica pterocarpa Hochst. ex A. Rich.	PH (L)	GC-Afro-Z
		Oreosyce africana Hook. f.	PH (L)	SZ
		Raphidiocystis phyllocalyx C. Jeffrey & Keraudren	PH (L)	SZ
		Raphidiocystis sp	PH (L)	SZ
		Zehneria scabra (L. f.) Sond.	PH (L)	Pal
Fabales	**Fabaceae**	*Acacia montigena* Brenan & Exell	PH (L)	A-O-Z
		Albizia gummifera (J. F. Gmel.) C. A. Sm.	MGPH	A-M
		Anthonotha lamprophylla (Harms) J.Leonard	PH	SZ-GC
		Baphia sp	PH (L)	A-trp
		Cassia didymobotrya Fresen.	PH	A-O-Z
		Dalbergia lactea Vatke	PH (L)	A-trp
		Desmodium repandum (Vahl) DC.	TH	Pal
		Desmodium velutinum (Willd.) DC.	TH	Pal
		Dumasia villosa DC.	TH	Pal
		Erythrina abyssinica Lam. ex DC.	PH	A-O-Z
		Leptoderris sp. Dunn	PH (L)	A-trp
		Millettia psilopetala Harms	PH	GC
		Newtonia buchananii (Baker f.) G.C.C. Gilbert & Boutique	MGPH	SZ-Afro
		Phaseolus sp	TH	Pan
		Vigna luteola (Jacq.) Benth.	TH	Pal
	Polygalaceae	*Carpolobia alba* G. Don	PH	GC
		Carpolobia goetzei Gürke	PH	SZ-M
		Carpolobia sp	PH	SZ-M
		Polygala ruwenzoriensis Chodat	TH	GC

Rosales	**Cannabaceae**	*Celtis african*a Burm. f.	PH	A-SAR-UZ-M
		Celtis gomphophylla Baker	PH	A-trp-UZ-Cm
		Trema orientale (L.) Blume	MSPH	Pal
	Moraceae	*Dorstenia brownii* Rendle	TH	SZ
		Dorstenia nyungwensis Troupin	TH	GC
		Dorstenia psilurus Welw.	TH	SZ
		Ficus asperifolia Miq.	PH (L)	A-trp
		Ficus exasperata Vahl	PH (L)	A-trp-M
		Ficus natalensis Hochst.	PH (L)	A-trp
		Ficus ottoniifolia (Miq.) Miq.	PH	GC
		Ficus sp 1	PH (L)	A-trp
		Ficus sp 2	PH (L)	A-trp
		Ficus sur Forssk.	PH	A-trp-SAR-UZ
		Ficus thonningii Blume	MGPH	A-trp-UZ
		Ficus vallis-choudae Delile	MSPH	A-trp
		Trilepisium madagascariense DC.	MGPH	A-trp
	Rhamnaceae	*Gouania longispicata* Engl.	PH (L)	A-trp
		Maesopsis eminii Engl.	MGPH	SZ
	Rosaceae	*Alchemilla kiwuensis* Engl.	TH	SZ-Afro-UZ-M
		Prunus africana (Hook. f.) Kalkman	PH	SZ-Afro-UZ-M
		Rubus sp	PH (L)	COS
	Urticaceae	*Boehmeria nivea* (L.) Gaudich.	TH	EX
		Boehmeria platyphylla Buch.-Ham. ex D. Don	TH	EX
		Droguetia iners (Forssk.) Schweinf.	TH	A-trp- SAR
		Elatostema monticola Hook. f.	TH	SZ-Afro
		Elatostema reticulatum Wedd.	TH	
		Laportea alatipes Hook. f.	TH	GC-Afro-UZ
		Musanga leo-errerae Hauman & J. Léonard	PH	GC
		Myrianthus holstii Engl.	PH	A-trp
		Pilea bambuseti Engl.	TH	GC
		Pilea johnstonii Oliv.	TH	GC-Afro-Z

			Pilea rivularis Wedd.	TH	SZ-Afro-SAR-M
			Pilea tetraphylla (Steud.) Blume	TH	SZ-Afro-SAR-M
			Urera hypselodendron auct.	PH (L)	GC-Afro-Z
			Urera trinervis (Hochst.) Friis & K.Immelman.	PH (L)	A-trp-UZ
Malvids	**Geraniales**	**Melianthaceae**	*Bersama abyssinica* Fresen.	PH	A-trp
			*Bersama abyssinica subsp. paullinioide*s auct.	PH	A-trp
	Myritales	**Melastomataceae**	*Calvoa orientalis* Taub.	TH	GC-Z
			Cincinnobotrys oreophila Gilg	TH	GC-Z-UZ
			Dichaetanthera corymbosa (Cogn.) Jacq.-Fél.	PH	SZ
			Dissochaeta monticola Blume	TH	GC
			Dissotis brazzae Cogn.	TH	A-trp
			Memecylon walikalense A. Fern. & R. Fern.	PH	GC
			Tristemma mauritianum auct.	TH	A-trp-M-Cm
		Myrtaceae	*Eucalyptus sp*	PH	EX
			Psidium guajava L.	PH	Am-trp
			Syzygium guineense D.C	PH	A-trp
	Brassicales	**Capparaceae**	*Capparis sp.*	PH (L)	Pal
			Ritchiea albersii Gilg	PH	A-trp
	Malvales	**Malvaceae**	*Cola pierlotii* R. Germ.	PH	GC
			Dombeya torrida (J. F. Gmel.) Bamps	PH	GC-Afro
			Grewia mildbraedii Burret	PH	GC-Z
			Grewia sp.	PH	GC-Z
			Hibiscus ludwigii Eckl. & Zeyh.	PH	GC-Afro-UZ
			Pavonia kilimandscharica Gürke	TH	GC-Afro-Z
			Pavonia urens Cav.	TH	GC-Afro-Z-M
			Sida cordifolia L.	TH	Latin-America
			Sida rhomboidea Roxb. ex Fleming	TH	Pal
			Triumfetta cordifolia A. Rich.	TH	GC-Afro-Z
			Triumfetta rhomboidea Jacq.	TH	Pal
		Thymeleaceae	*Peddiea fischeri* Engl.	PH	A-trp
	Sapindales	**Anacardiaceae**	*Pseudospondias sp.*	PH	A-trp-Cm
			Rhus vulgaris auct.	PH	A-O-Z

		Trichoscypha lucens Oliv.	PH	GC
	Meliaceae	*Carapa grandiflora* Sprague	PH	GC-Z
		Carapa spec nov	PH	GC
		Cedrela serrata Royle	PH	I-A
		Ekebergia capensis Sparrm.	PH	A-trp-UZ
		Entandrophragma excelsum (Dawe & Sprague) Sprague	PH	GC-Afro-Z
		Guarea cedrata (A. Chev.) Pellegr.	PH	GC
		Lepidotrichilia volkensii (Gürke) Leroy	PH	A-O-Z
		Trichilia emetica Vahl	PH	A-Tr-UZ-AP
		Turraea floribunda Hochst.	PH	Z-UZ
		Turraea vogelioides Bagsh. & Baker f.	PH	GC
	Rutaceae	*Clausena anisata* (Willd.) Hook. f. ex Benth.	PH	A-trp-UZ
		Fagaropsis angolensis (Engl.) Dale	PH	A-trp
		Toddalia asiatica (L.) Lam.	PH (L)	GC-Afro-Z
		Vepris nobilis (Delile) Mziray	PH	A-O-Z
		Zanthoxylum gilletii (De Wild.) P. G. Waterman	PH	A-trp
	Sapindaceae	*Allophylus chaunostachys Gilg*	PH (L)	Z
		Allophylus kivuensis Gilg	PH (L)	A-trp
		Allophylus sp	PH (L)	A-trp
		Allophylus sp1	PH (L)	A-trp
		Allophylus sp2	PH (L)	A-trp
		Blighia unijugata Baker	PH (L)	A-trp-UZ
		Cardiospermum halicacabum L.	PH (L)	Pal
		Deinbollia kilimandscharica Taub.	PH	A-O-Z
		Pancovia golungensis (Hiern) Exell & Mendonça	PH	Z-UZ
		Paullinia pinnata L.	PH (L)	Pan
		Zanha golungensis Hiern	PH	A-trp
Santalales	**Balanophoraceae**	*Thonningia sanguinea* Vahl	G	A-trp
	Loranthaceae	*Agelanthus musozensis* (Rendle) Polhill & Wiens	E (L)	GC-Afro
		Viscum sp.	E (L)	Pal

	Strombosiaceae	*Strombosia scheffleri* Engl.	PH	SZ
Caryophyllales	**Amaranthaceae**	*Achyranthes aspera* L.	TH	Pal
		Celosia schweinfurthiana Schinz.	TH	A-O-Z
		Celosia sp	TH (L)	A-O-Z
		*Sericostachys scanden*s Gilg & Lopr.	PH (L)	A-trp
	Basellaceae	*Basella alba* L.	PH (L)	A-trp
	Cactaceae	*Rhipsalis baccifera* (J. S. Muell.) Stearn	E	Pan
	Caryophyllaceae	*Drymaria cordata* (L.) Willd. ex Roem. & Schult.	TH	Pan
	Phytolaccaceae	*Phytolacca dodecandra* L'Hér.	PH (L)	GC-Afro-Z-UZ-M
	Polygonaceae	*Harpagocarpus snowdenii* Hutch. & Dandy	TH	SZ
		Polygonum nepalense Meisn.	TH	A-O-UZ-M-Trp Asia
Cornales	**Cornaceae**	*Alangium chinense* (Lour.) Harms	PH	GC-SZ-Afro-TrAsia
Ericales	**Balsaminaceae**	*Impatiens burtonii* Hook. f.	TH	A-trp
		Impatiens erecticornis R. Wilczek & G. M. Schulze	TH	GC
		Impatiens hochstetteri Warb.	TH	A-trp-UZ
		Impatiens niamniamensis Gilg	TH	GC-SZ
		Impatiens sp	TH	
	Ebenaceae	*Diospyros abyssinica* (Hiern) F. White	PH	A-trp
	Primulaceae	*Ardisia kivuensis* Taton	PH	SZ
		Embelia libeniana Taton	PH (L)	GC
		Embelia schimperi Vatke	PH (L)	A-trp
		Maesa lanceolata auct.	PH	AS-trp
	Sapotaceae	*Aningeria altissima* (A. Chev.) Aubrév. & Pellegr.	PH	A-trp
		Chrysophyllum gorungosanum Engl.	PH	GC-Z
		Englerophytum natalense (Sond.) T. D. Penn.	PH	Z-UZ
		Manilkara obovata (Sabine & G. Don) J. H. Hemsl.	PH	A-trp
		Mimusops bagshawei S. Moore	PH	SZ
		Synsepalum sp. A. DC.	PH	A-trp

		Sladeniaceae	*Ficalhoa laurifolia* Hiern	PH	GC-Z-UZ
		Boraginaceae	*Ehretia cymosa* Thonn.	PH	SZ-Afro
Asterids	**Gentianales**	**Apocynaceae**	*Ceropegia sp*	PH (L)	Pal
Lamiids			*Cynanchum insipidum* (E. Mey.) Liede & Khanum	PH (L)	A-trp-UZ-KN-Cp
			Landolphia buchananii (Hallier f.) Stapf	PH (L)	A-trp
			Landolphia owariensis P. Beauv.	PH (L)	A-trp
			Landolphia sp	PH (L)	A-trp
			Motandra guineensis (Thonn.) A. DC.	PH (L)	GC-Z
			Pleiocarpa pycnantha (K. Schum.) Stapf	PH	GC
			Rauvolfia mannii Stapf	PH (L)	A-trp
			Rauvolfia sp	PH (L)	SZ
			Secamone africana (Oliv.) Bullock	PH (L)	SZ
			Secamone emetica var. glabra K. Schum.	PH (L)	
			Strophanthus bequaertii Staner & Michotte	PH (L)	GC
			Tabernaemontana odoratissima (Stapf) Leeuwenb.	PH (L)	Z
			Tabernaemontana stapfiana Britten	PH (L)	A-trp
			Tacazzea apiculata Oliv.	PH (L)	A-trp-UZ
			Tylophora sylvatica Decne.	PH (L)	A-trp-M
		Loganiaceae	*Anthocleista grandiflora* Gilg	PH	SZ-UZ-Cm
			Strychnos lucens Baker	PH (L)	GC-Z
			Strychnos potatorum L. f.	PH (L)	Z-M
		Rubiaceae	*Aidia micrantha* (K. Schum.) F. White	PH	GC-Z
			Chassalia subochreata (De Wild.) Robyns	PH	GC-Z
			Coffea eugenioides S.Moore.	PH	SZ
			Coffea sp	PH	SZ
			Galiniera saxifraga (A.Rich) Bridson	PH	A-trp
			Heinsenia diervilleoides K. Schum.	PH	SZ
			Hymenodictyon sp.	E (L)	A-trp-UZ-M
			Ixora burundiensis Bridson	PH	GC
			Keetia gueinzii (Sond.) Bridson	PH	GC-Afro-UZ
			Mussaenda arcuata Lam. ex Poir.	PH	A-trp
			Oxyanthus speciosus DC.	PH	A-trp-UZ

		Oxyanthus troupinii Bridson	PH	GC
		Pauridiantha paucinervis (Hiern) Bremek.	PH	SZ-Afro-M
		Pavetta pierlotii Bridson	PH	GC
		Pavetta rwandensis Bridson	PH	GC
		Pseudosabicea arborea (K. Schum.) N. Hallé	PH	Z
		Psychotria avakubiensis De Wild.	PH	GC
		Psychotria ceratoloba (K. Schum.) O. Lachenaud	PH	GC
		Psychotria ealaensis De Wild.	PH	A-trp
		Psychotria lebrunii Cheek	PH	GC
		Psychotria mahonii C. H. Wright	PH	SZ
		Psychotria punctata Vatke	PH	GC
		Psychotria nigropunctata Hiern	PH	GC-Z
		Psychotria peduncularis (Salisb.) Steyerm.	PH	A-trp
		Psychotria parvistipulata E.M.A. Petit	PH	GC
		Rothmannia urcelliformis (Hiern) Robyns	PH	A-trp
		Rubia cordifolia L.	TH	COS
		Rubiaceae sp	PH (L)	
		Rutidea fuscescens Hiern	PH (L)	A-O-Z
		Rutidea orientalis Bridson	PH (L)	A-O-Z
		Rutidea smithii Hiern	PH	A-O-Z
		Rytigynia bugoyensis (K. Krause) Verdc.	PH	GC-Z
		Rytigynia kivuensis (Krause) Robyns.	PH	
		Rytigynia ruwenzoriensis (De Wild.) Robyns	PH	GC
		Spermacoce princeae (K.Schum) Verdc.	TH	A-trp
		Tarenna pavettoides (Harv.) Sim	PH	A-trp-U
		Tricalysia sp1	PH	
		Tricalysia sp2	PH	
		Vangueria apiculata K. Schum.	PH	A-O-Z
		Vangueria sp	PH	A-O-Z
		Virectaria major (K. Schum.) Verdc.	TH	A-trp
Lamiales	**Acanthaceae**	*Acanthaceae sp1*	TH	
		Acanthaceae sp2	TH	

		Acanthaceae sp3	TH	
		Acanthopale confertiflora (Lindau) C.B. Clarke	TH	A-O-Z
		Brillantaisia cicatricosa Lindau.	TH	SZ
		Hypoestes forskahlei Vahl	TH	A-trp-SAR
		Hypoestes triflora (Forssk.) Roem. & Schult.	TH	A-trp-SAR-U
		Justicia scandens Vahl	TH	A-trp-UZ-M
		Mimulopsis arborescens C.B. Clarke	TH	GC-Afro-Z
		Mimulopsis solmsii Schweinf.	TH	A-trp
		Pseuderanthemum lindavianum De Wild. & T.	TH	GC-Z
		Thunbergia alata Bojer ex Sims	PH (L)	A-trp-UZ-M
		Thunbergia vogeliana Benth.	PH (L)	SZ
	Bignoniaceae	*Kigelia aethiopica* Decne.	PH	A-trp-UZ
		Kigelia africana (Lam.) Benth.	PH	Z
		Markhamia lutea (Benth.) K. Schum.	PH	SZ
		Spathodea campanulata P. Beauv.	PH	GC-Z
	Lamiaceae	*Clerodendrum sp*	PH (L)	Pal
		Clerodendrum buchananii (Roxb.) Walp.	PH (L)	
		*Clerodendrum buchholzi*i Gürke	PH (L)	A-trp
		Clerodendrum bukobense Gürke	PH (L)	SZ
		*Clerodendrum johnstoni*i Oliv.	PH (L)	A-O-Z
		Isodon ramosissimus (Hook. f.) Codd	TH	A-trp
		Motandra guineensis (Thonn.) A. DC.	PH (L)	GC-Z
		Plectranthus luteus Gürke	TH	GC-Z-M
		Premna angolensis Gürke	PH	A-trp
		Vitex doniana Sweet	PH	A-trp
	Oleaceae	*Chionanthus mildbraedii* (Gilg & G.Schellenb.)	PH (L)	SZ-Afro
		Chionanthus sp.	PH (L)	
		Jasminum abyssinicum Hochst. ex DC.	PH (L)	GC-Afro-UZ
		Jasminum sp	PH (L)	
	Scrophyllariaceae	*Stellaria sennii* Chiov.	TH	GC-Afro-Z
Solanales	**Convolvulaceae**	*Ipomea sp*	PH (L)	
	Solanaceae	*Cyphomandra betacea* (Cav.) Sendtn.	PH	EX

			Solanum chrysotrichum Schltdl.	PH	SZ
			Solanum nigrum L.	TH	COS
			Solanum plousianthemum Dammer	PH (L)	A-trp-SAR-U
Campanulids	**Aquifoliales**	**Aquifoliaceae**	*Ilex mitis* (L.) Radlk.	PH	A-trp-UZ-M
		Cardiopteridaceae	*Leptaulus* sp. Benth	PH	A-trp-M
	Asterales	**Asteraceae**	*Adenostemma mauritianum* DC.	TH	A-trp
			*Ageratum conyzoide*s L.	TH	COS
			Bothriocline nyungwensis Wech.	TH	GC
			Conyza sumatrensis (Retz.) E. Walker	TH	Pan
			Crassocephalum montuosum (S. Moore)	TH	A-trp
			Dichrocephala latifolia (Lam.) DC.	TH	COS
			Galinsoga ciliata (Raf.) S. F. Blake	TH	Pan
			Gynura scandens O. Hoffm.	PH (L)	GC-Afro-Z
			Melanthera scandens (Schumach. & Thonn.)	TH	A-trp-KN
			Microglossa pyrifolia (Lam.) Kuntze	TH	Pal
			Mikania capensis DC.	PH (L)	A-trp-UZ-Cm
			Mikania sp	PH (L)	A-trp-UZ-Cm
			Mikaniopsis clematoides auct.	PH (L)	A-O
			Solanecio cydoniifolius (O. Hoffm.) C. Jeffrey	TH	Z
			*Solanecio manni*i (Hook.f.) C.Jeffrey	PH	SZ-Afro
			Solanecio sp	TH	A-trp
			Vernonia adolfi-friderici Muschl.	PH	GC
			Vernonia amygdalina Delile	PH	SZ-Afro
			Vernonia auriculifera Hiern	PH	Pan
			Vernonia cinerea (L.) Less.	TH	Pal
		Campanulaceae	*Canarina emini*i Asch. & Schweinf.	PH (L)	A-O-Z
			Lobelia giberroa Hemsl.	CH	A-O-Z
	Apiales	**Apiaceae**	*Oenanthe mildbraedii* H. Wolff	TH	A-trp
			Sanicula elata Buch-Ham. ex D. Don	TH	A-O-SAR-A
		Araliaceae	*Polyscias fulva* (Hiern) Harms	PH	A-trp-SAR
			Schefflera abyssinica (Hochst. ex A. Rich.) Harms	E (L)	SZ-Afro
			Schefflera goetzenii Harms	E (L)	SZ

Pittosporaceae	*Pittosporum spathicalyx* De Wild.	PH	A-trp-SAR-U-M

4.4. Species richness

4.4.1 Alpha-diversity in physiognomic communities

Initially, local differences were observed in physiognomic communities at Cyamudongo and Gasumo study areas where α-diversity values differed within and among communities. The taxonomic composition of species varied greatly as presented from figure 20 to 23 and α-diversity varied from one site to another in each community. There were moderate similarities between Gasumo and the buffer zone and secondary of Cyamudongo in terms of number of taxa which are established almost in the same interval. In these landscapes of Cyamudongo, the species richness was higher with a number of taxa almost established in the same interval of [20-45] in comparison to the primary forest with a number of the taxa ranging from 25 to 37. The species richness of this initial phase of should have been influenced by the seasonal effect as the study covered the period of mid long dry season up the end of the short dry season of 2018.

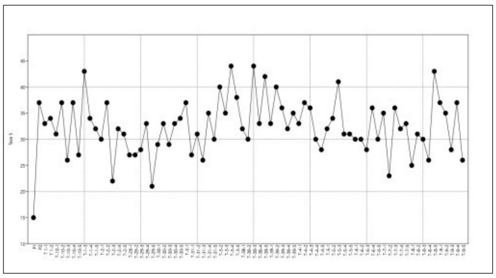


Figure 20: Initial taxa richness in BZ

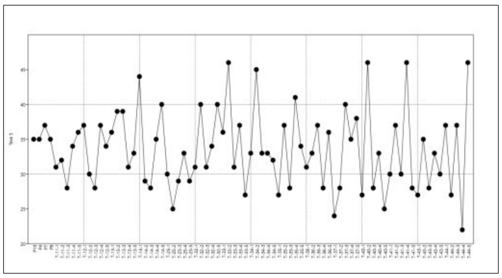


Figure 21: Initial taxa richness in the SF

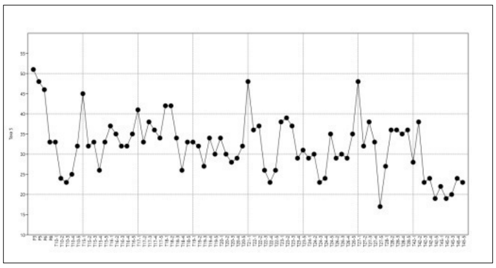


Figure 22: Initial taxa richness in in PF

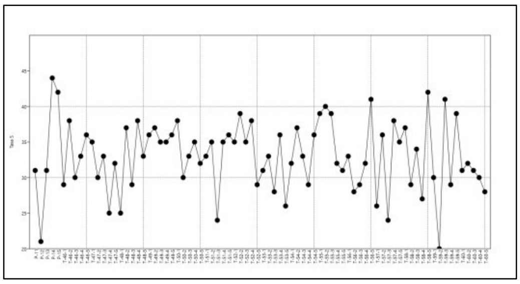


Figure 23: Initial taxa richness at GS

The general trends read on graphs show that the primary forest and the buffer zone were more or less homogenous than the secondary forest of Cyamudongo and Gasumo exhibiting longest amplitude and deformation. The intermediary phase of the study depicted changes in flora composition as presented at figure 23-27.

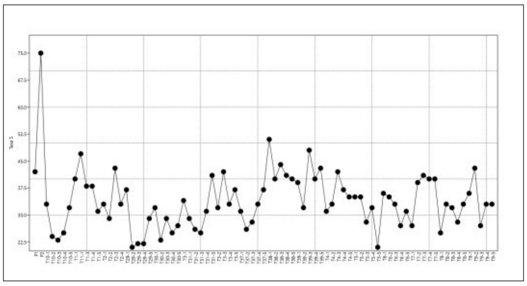


Figure 24: Phase II taxa richness in BZ

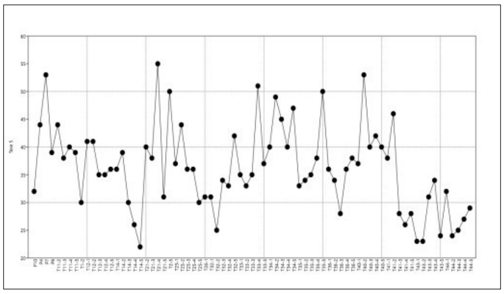


Figure 25: Phase II taxa richness in SF

The general trends read on figures 20-23 showed almost heterogeneity in species composition in terms of number of species established in different intervals with a high frequency of longest amplitudes in the secondary forest than other types of forest. The species diversity has increased slightly in both buffer and secondary zones of Cyamudongo forest and while longest amplitudes at Gasumo have decreased. On the other hand, in the primary forest, the α-diversity decreased and the species numbers in most of plots ranged from 17 to 40 with a very low variability than in other communities. The dynamic and difference in species richness at the level of/ among landscapes reflected differences and similarities in the studied communities and the sampling period effect covering the period of short rain season 2019.

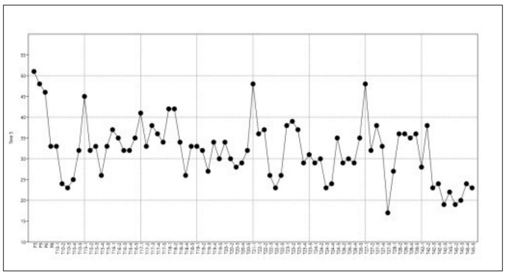


Figure 26: Phase II taxa diversity in PF

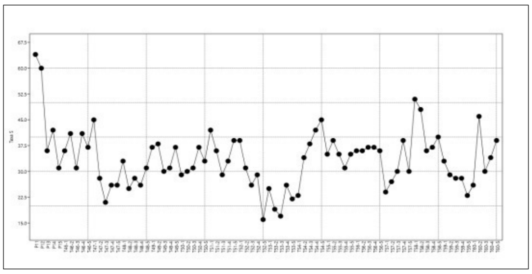


Figure 27: Phase II taxa richness at GS

Trends in species richness at the final phase of the study are reflected by figure 28-31.

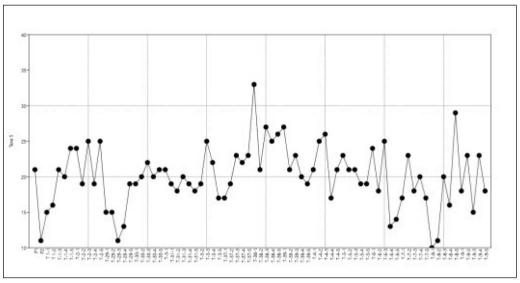


Figure 28: Phase III taxa diversity in BZ

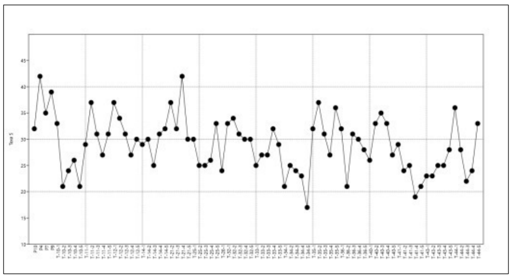
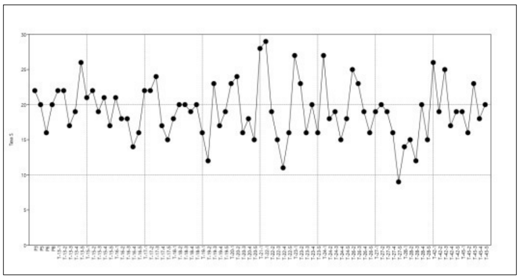


Figure 29: Phase III taxa richness in SF



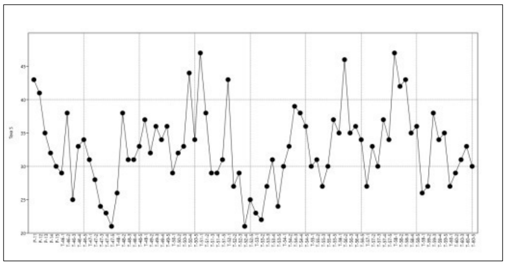


Figure 30: Phase III taxa richness in PF **Figure 31: Phase III taxa richness at GS**

Figures 20-31 provided an overview of taxa number distribution over different communities in Cyamudongo landscapes and Gasumo sampled areas of Nyungwe main block in the three phases of the study. The general trends of the last phase witness the effect of the long dry season of 2020 as the survey covered the period of September-October 2020. Results portrayed a highest heterogeneity in samples secondary forest of Cyamudongo and Gasumo than the buffer zone and the primary forest. In addition, a general decrease of α-diversity is observed in primary forest and the buffer zone where the richness is established in the interval [13-27(8)] and in the interval [20- 45] for the secondary forest and Gasumo study areas.

4.4.2 Beta diversity in physiognomic communities and Gasumo

The species diversity of Cyamudongo physiognomic communities and Nyungwe study are described by beta diversity to give an overview of different possible differentiations to be drawn from sampled areas basing on species inventories as previously postulated by Velland (2001). The global β-diversity suggested by Whittaker was found to be 28, 13 and 17 for respectively the initial, intermediate and the final phase of the study. These β-diversity values mean approximately same number of distinct communities. If Beta diversity is greater than 6, most of the communities overlap and hinder their visualizations. Consequently, the obtained β-diversities in all the three phases of the study suggested overlaps of species communities. It was not sufficient to analyze the forest entirely as the data was recorded basing on physiognomic communities and extract useful findings that give us an insight of the forest. In this section, the results of beta diversity of the primary forest, secondary forest buffer zone and Gasumo are presented at table 14 with differences in local species assemblages.

Table 16: Beta diversity of physionomic communities of Cyamudongo and the study area of Nyungwe

Global ß-diversity				
Samples	BZ	SF	PF	GS
Phase I	14	15	15	12
Phase II	8	12	10	10
Phase III	9	10	9	9

In the table 16, β-diversity was found to be the same and the highest in primary and secondary forests and the lowest at Gasumo at the initial phase of the study. A decrease in β-diversity has been observed from 2017 to 2020 in all forest communities. The decrease observed is higher in all the components at Cyamudongo than at Gasumo and the secondary forest maintained the highest β-diversity. This may imply that rare species were occurring more in primary and secondary forests as well as in the buffer zones.

The decline of beta-diversity should suggest reduction of disturbance impact in all landscapes within species assemblages. Moreover, the obtained beta-diversity values remain high explaining the heterogeneity in community structures.

4.4.3 Species evenness among study landscapes

The evenness results for the three phases of the study as presented from figure 34 to figure 43 presented high levels of evenness for different sites. These high levels of evenness indicate more richness in the study areas while evenness curve fluctuations signify heterogeneity in species composition among study sites. At the other hand, same levels of evenness values reflected the same relative abundance and perfectly even community composition. At the initial phase of the study, the buffer zone has shown a complete evenness in some plots with species evenly abundant and variability in relative abundance explained by considerable high amplitude differences on evenness curve by comparison with other physiognomic groups.

Moreover, the primary and Gasumo forest physiognomies were found with a good level of homogeneity in the species relative abundance and the later in close similarity with the secondary forest of Cyamudongo. The evenness described at figure 32-35 present a higher variability in the samples of the secondary forests and buffer zones than the primary and Gasumo forests. The evenness was found to be high even though fluctuations are observed with the evenness almost perfect even and above 0.9.

However, curves of evenness of the intermediary dataset display more fluctuations as presented at figure 32-36. In this study period, trends lines of evenness show more heterogeneity in species relative abundance. All sites are above average evenness value which was very high in all physiognomic communities studied and ranging between 0.75 and 1. Buffer zones were found with shortest amplitude differences and less variable for the species relative abundance and other physiognomic communities.

At the intermediate phase of the study, all physiognomic communities experienced changes according to evenness curves presented at figure from 36 to 39. The primary, the secondary forest and Gasumo forest physiognomies appeared with a decrease in evenness with more heterogeneity while the buffer zones decrease evenness levels and tends to be homogenous.

In these communities, most of the plots have species that are evenly abundant while few of them are moderately evenly distributed as shown 36-39. Moreover, changes were observed in buffer zones with a decrease of evenness high value while the value increased in primary and secondary forests. The evenness trend line in buffer zone shows that species are more uniformly distributed than in others communities with more fluctuations of their trend lines. The 3rd phase of the study did show a big change in the buffer zone with almost the same species the intermediary phase of the study. However, the trend lines of primary forest and Gasumo are similar and more uniformly distributed than the secondary forest and the buffer zone physiognomies.

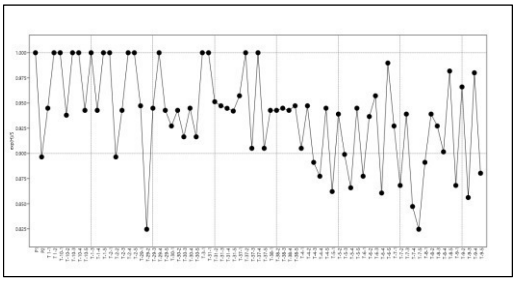


Figure 32: Initial species evenness of BZ

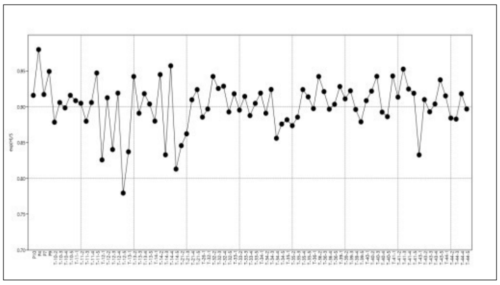


Figure 33: Initial species evenness of SF

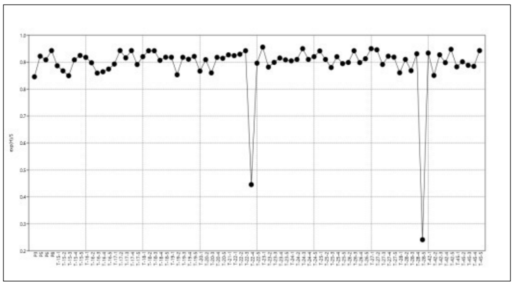


Figure 34: Initial species evenness of PF

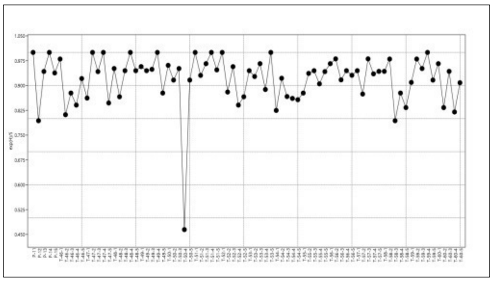


Figure 35: Initial species evenness of GS

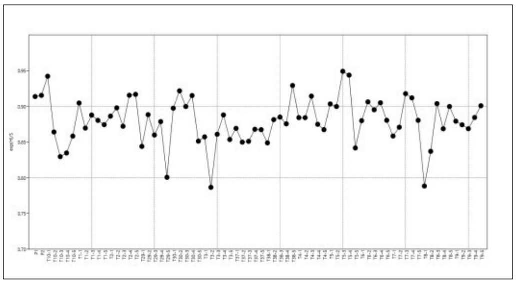


Figure 36: Intermediate evenness of BZ

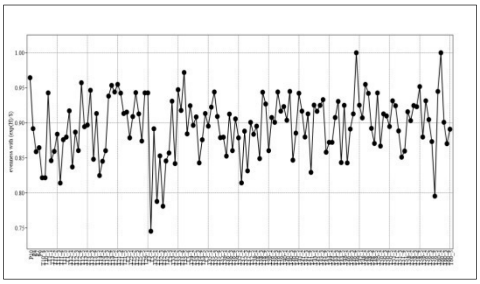


Figure 37: Intermediate evenness of the SF

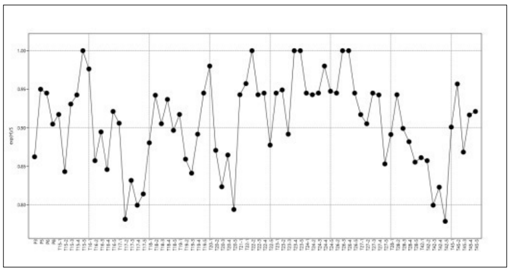


Figure 38: Intermediate evenness of PF

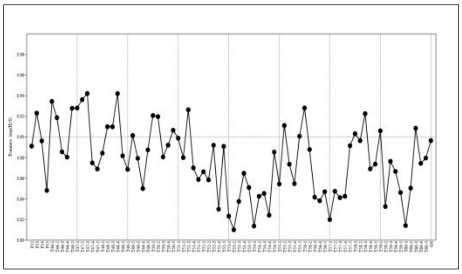


Figure 39: Intermediate evenness of GS

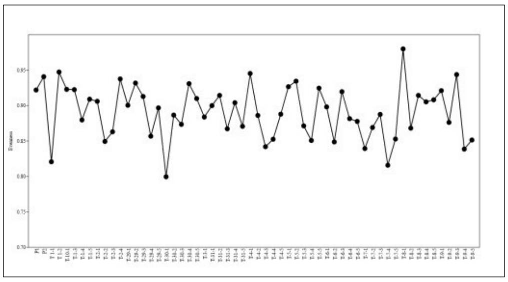


Figure 40: Final phase BZ evenness

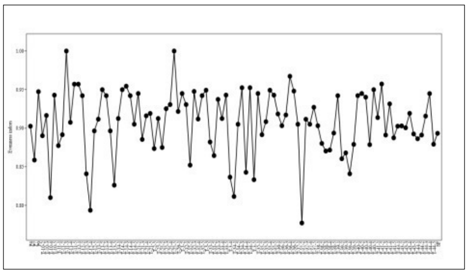


Figure 41: Final phase SF evenness

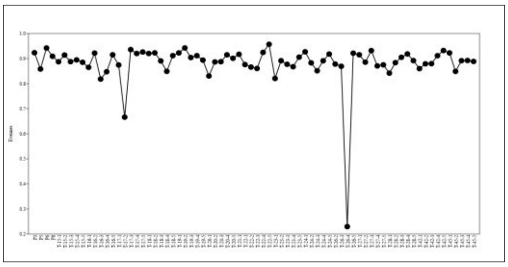


Figure 42: Final phase PF evenness

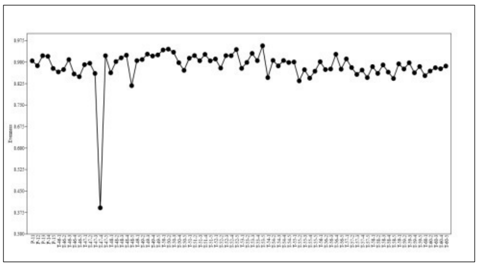


Figure 43: Final phase GS evenness

4.4.5 Diversity according Simpson index

The table 17 presents minima and maxima indices of diversity according to Simpson diversity in the study period.

Table 17: Ranges of Simpson indices of diversity in the study phases

Key: FT= Forest types, L= Low value, H= high value, M= magnitude at phase 1, 2 and 3.

FT	Phase I			Phase II			Phase III		
	L1	H 1	M1	L2	H 2	M2	L3	H 3	M3
BZ	0	0.87	0.87	0.88	0.96	0.08	0.77	0.95	0.18
SF	0.82	0.95	0.13	0.7	0.94	0.24	0.45	0.94	0.49
PF	0.81	0.94	0.13	0.45	0.96	0.51	0.44	0.96	0.52
GS	0.85	0.95	0.1	0.84	0.97	0.13	0.6	0.97	0.37

According to table 15 and the corresponding Simpson indices trend lines at the initial stage of data collection, the diversity was found high at almost of all the sampled areas of secondary and primary physiognomic communities as well as at Gasumo sampled landscape. This diversity reduced slightly and established their lowest Simpson index values respectively at 0.7; 0.45 and 0.84 (Table 15). The buffer zone (**Fig.45**) showed initially plots whose diversity indices were presented once with no diversity and not associated to others. This is because of difference in buffer zone where even the afforestation was based on different species including exotics that may have impacted the natural regeneration. The situation reversed where the initial diversity increased significantly and ranged between 0.88 and 0.96 at the intermediate phase of the study (**fig.49**). These probabilities displayed are those that each sample owns relative to the rest and showed how equitable the species abundance is clearly indicated. Moreover, the intermediate stage of the study indicates a significant level of similarity between the plots encompassing the buffer zone forest landscape since probabilities are ranging between 90% and 95%; except two of plots in contrast with probabilities between 75% and 90% but not far from others considering the difference and the significance.

Though in secondary forest, most of the plots have sufficient probabilities to be included in one sample two by two at time, there is a difference seen at the figure.49 as the fluctuation is persistent there. Although, the diversity has increased and Simpson indices established at the same level for both the initial and the intermediate phase.

At the final phase of the study (figure 53), plenty of the plots are likely to be similar since many of them have the probability ranging between 0.85 and 0.9 while others are below this probability. Communities seem to separate into different communities due to differences in probability values among samples.

Most of the plots in primary forest were similar with enough probability due to their species composition and the closest diversity index values that reflect the PCA figure that showed that the entire sample showed a significant similarity that pushed them at the center. In general, the trend lines of Simpson diversity explain the highest diversity with hyper dominance at Gasumo and similarity in plots. Some plots need to increase in species diversity to maximize the similarity among samples. The trend lines of the primary forest show a more homogenous and high diversity at all the three phases of the study and mostly at the final phase of the study and similar trend with Gasumo at the final phase of the study.

The primary and Gasumo forest were likely to be homogenous. The heterogeneity increased in secondary forest while the buffer zone shortened and become more homogenous during the study period as presented at figure 44.

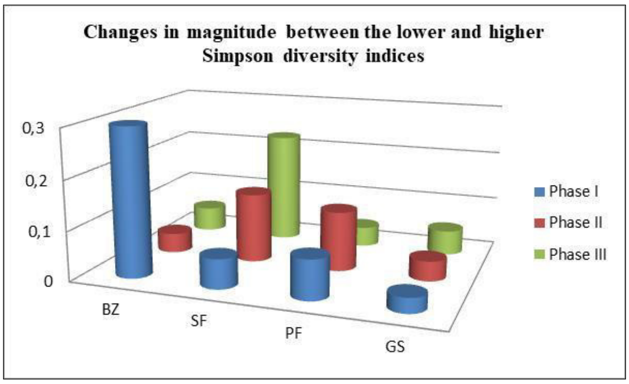
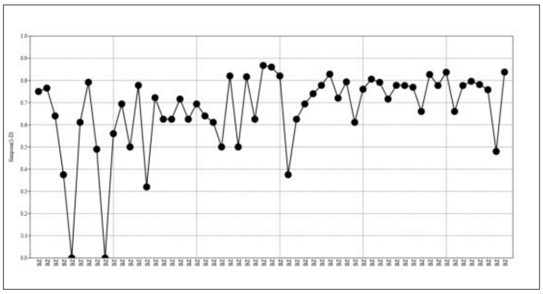


Figure 44: Trends of community diversity and homogeneity

The trend lines of Simpson diversity for the three phases of the study are presented at figure 45-56.



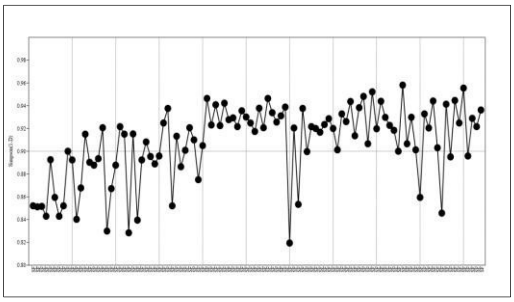


Figure 45: Phase I Simpson diversity of BZ **Figure 46: Phase I Simpson diversity of the SF**

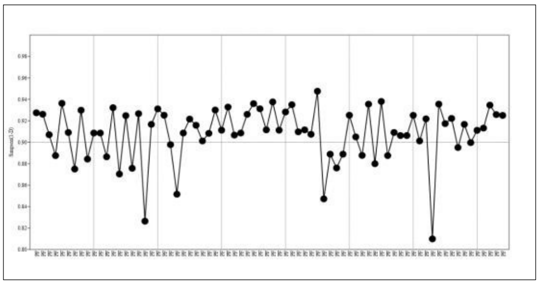


Figure 47: Phase I Simpson diversity of PF

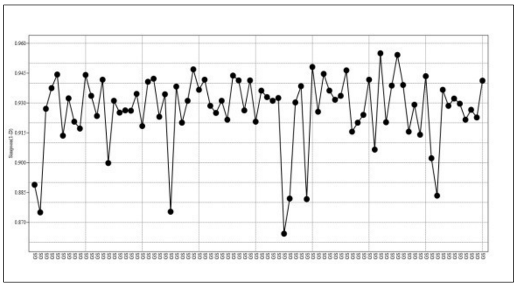


Figure 48: Phase I Simpson diversity of GS

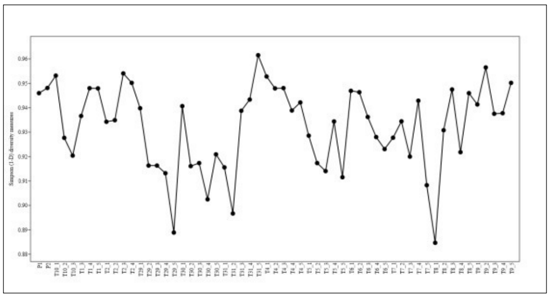


Figure 49: Phase II Simpson diversity of BZ

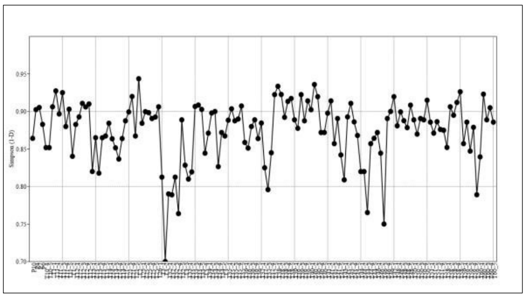


Figure 50: Phase II Simpson diversity of SF

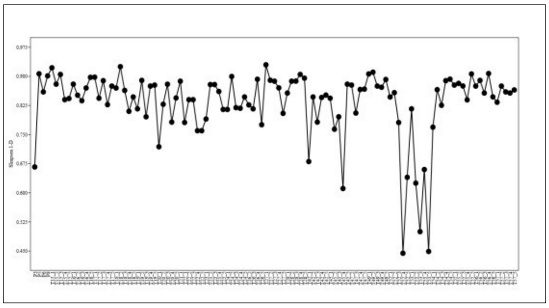


Figure 51: Phase II Simpson diversity of PF

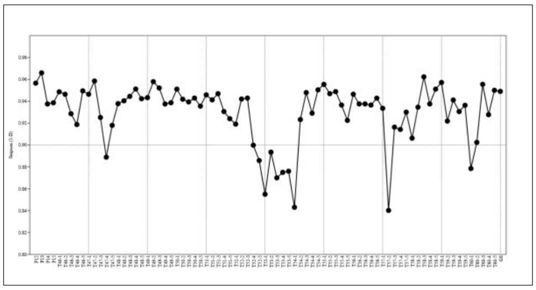


Figure 52: Phase II Simpson diversity of GS

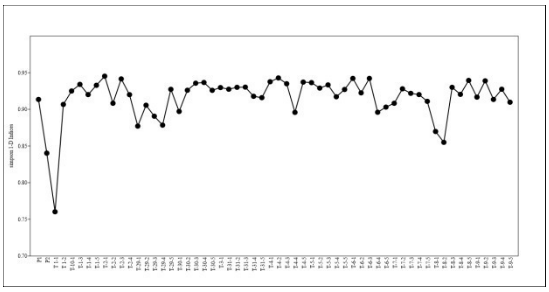


Figure 53 Phase III Simpson diversity of BZ

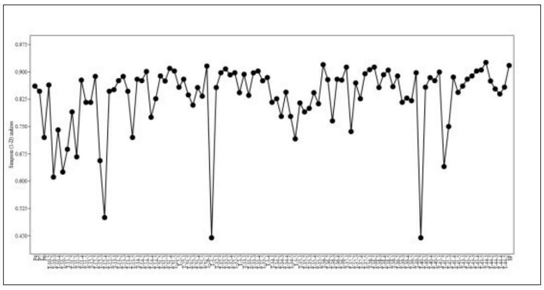
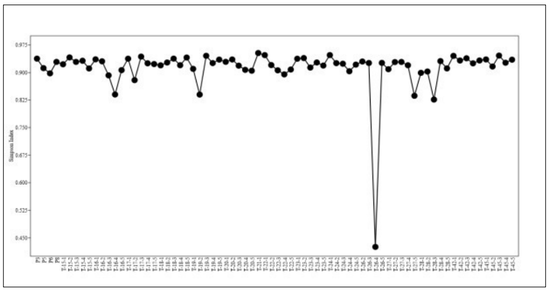


Figure 54: Phase III Simpson diversity SF



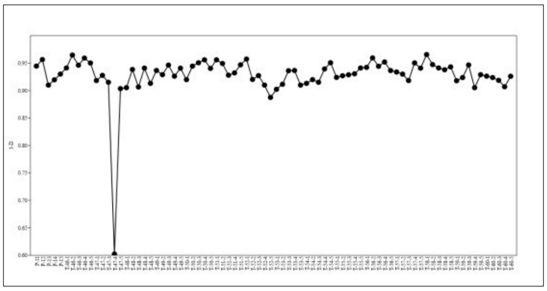


Figure 55: Phase III Simpson diversity of PF **Figure 56: Phase III Simpson diversity of GS**

The subsequent results as presented above with figure.49-56 to the initial survey showed that the diversity increased substantially in the buffer zone, while dropped slightly in the secondary and primary forests with the tendency to homogenize and increase high at Gasumo.

4.4.6 Shannon entropy and patterns in ecology

The trend of the Shannon–Wiener diversity index was different in all forest communities as observed for the species richness, evenness and the Simpson diversity. Initially, the index was the lowest in the buffer zones and the highest at Gasumo. The primary forest tended to be homogenous over the secondary forest explaining more variability in species diversity composition. As the CCA indicated, the buffer zone was being affected by disturbances with a huge magnitude and it was reflected in the level of entropy that indicates that the buffer zone was still disordered even in the intermediate vegetation survey (**fig.**61). At the final stage, the degree of the entropy in buffer zone forest was found high compare to the primary and secondary forest with the means of 2.5, and most of the plots are above level two and less disorder.

Initially, the entropy ranged from 1.8 to 3.5 with so many fluctuations in secondary forest that indicate a significant trend of variability of the species diversity. A decrease was observed and the level of entropy established between 1.4 to 2.8 with a lot plots that the level of disorder ranged from 1.6 to 2.5 and showed no significant trend or fluctuations. This gives an insight of how positively the forest has been impacted on by reducing the level of disturbance which was impaired with the decrease in species diversity. Although, the levels of disorder for most of the plots ranges in between 1.0 and 2.0 at phase three of the study which implies a decrease of the diversity.

Shannon indices changed in primary forest where the level of disturbance before was ranging between 1.8 and 3 with much of plots to be in 2.2-2.8 at the initial phase as shown at figure 59. At the intermediate phase, the level of entropy dropped to 1- 2.5 with so many plots stable between 1.5 -2.5. This indicates a significant change in this forest that was highly disordered toward the healthy one. Moreover, the level of entropy at figure. 67 gives the information that many of the plots possess the same level of entropy. This is thought to be similar to the evenness indices previously computed where the trend line showed that the species are equally distributed in the primary forest and reflects almost the equality in species diversity.

At Gasumo, the wide range of disorder was found in a range of 2.55 to 3 and the maximum entropy was equals to 3.2 and the minimum 2.20. These values increased slightly and most of the plots were found to be in the range between 2.6 and 3.2 with the highest being 3.5 and the lowest 2. At last phase of the study, the degree of the entropy in Gasumo forest is high meaning a high diversity compared to the primary and secondary forests with the means of 3, and most of the plots are above level 2.5. The increase of the species diversity in Gasumo forest is impaired with the increase in disorder and persistent disturbance at Gasumo also contributing hugely to the increase in entropy in this area. Actually, the increase in species composition leads to high beta diversity which may be due to the occurrence some species in a community caused by the increase in level of disturbance. On the other hand, there are species that were under development due to the disturbance and the reduction of the canopy that was given a time to grow and are responsible for the communities' distinction and increased the entropy. Figure57-68 displayed the trend line of Shannon indices of the studied areas.

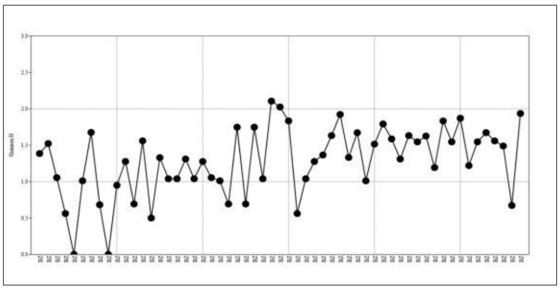


Figure 57: Initial entropy of the BZ

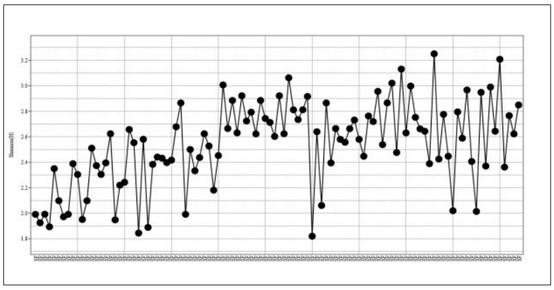


Figure 58: Initial entropy of the SF

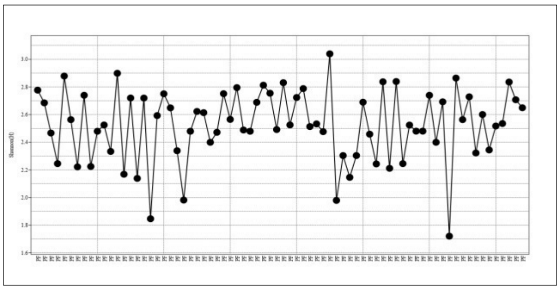


Figure 59: Initial entropy of PF

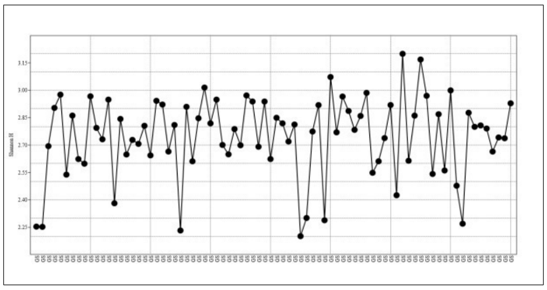


Figure 60: Initial entropy of GS

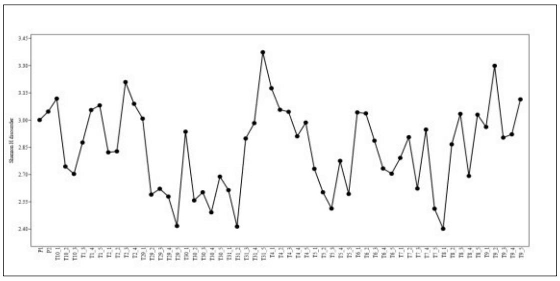


Figure 61: Intermediate entropy of BZ

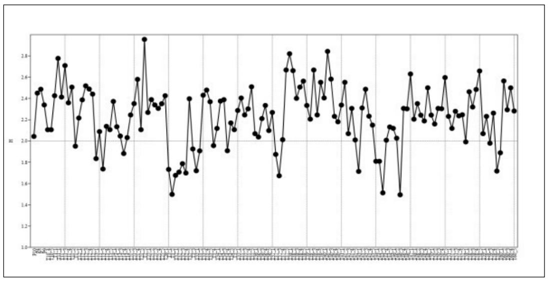


Figure 62: Intermediate entropy of the SF

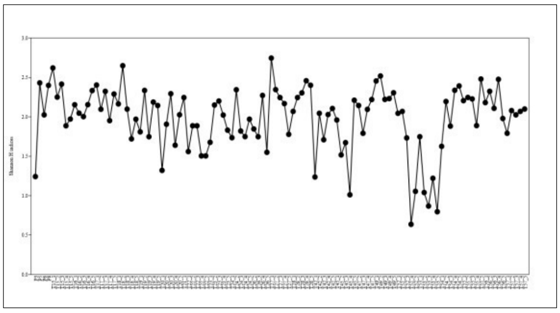


Figure 63: Intermediate entropy of PF

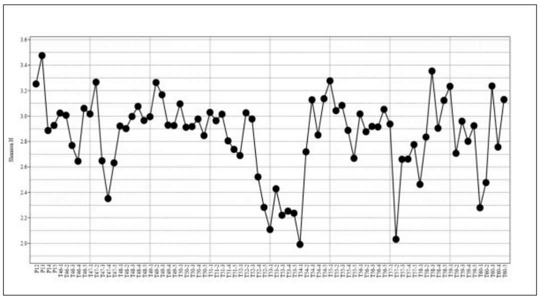


Figure 64. : Intermediate entropy of GS

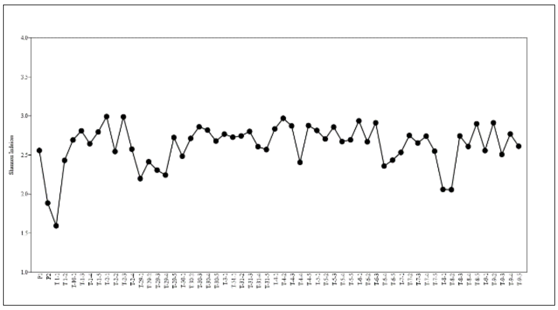


Figure 65: Final phase entropy of BZ

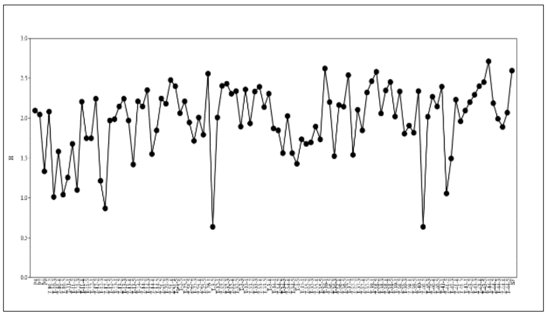


Figure 66: Final phase entropy of SF

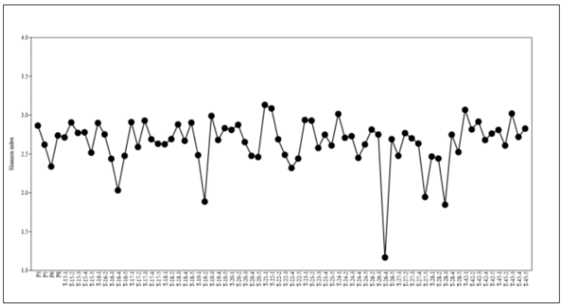


Figure 67: Final phase entropy of PF

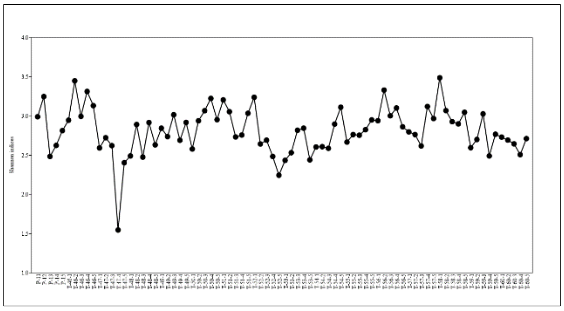


Figure 68: Final phase entropy of GS

In summary, trend lines of Shannon indices show differences among studied communities and changes from one phase to another in the study period while there are a close similarity between the primary forest and Gasumo study area. In addition, Shannon indices increased in the buffer zones and have almost decreased in primary forest and Gasumo while these indices first decreased and increased at the final stage of the research in the secondary forest. Further the difference between lower and higher Shannon indices values as presented at table 18 show in which range the diversity is estimated and the extend of the disorder.

Table 18: Shannon indices and magnitude among study communities

FT	Phase I			Phase II			Phase III		
	L	H	Magnitude	L	H	Magnitude	L	H	Magnitude
BZ	0	2,1	2,1	2,4	3,35	0,95	1,6	3	1,4
SF	1	3,2	2,2	1,5	2,9	1,4	0,6	2,6	2
PF	1,7	2,9	1,2	0,6	2,8	2,2	1,1	3,3	2,2
GS	2,3	3,3	1,05	2	3,5	1,5	1,5	3,4	1,9

According to table 17, the magnitude differed from the study period to the other one, by increase in the primary forest and Gasumo and a decrease in buffer zone and secondary forest which may be explained by seasonal variation.

4.5 Similarity among physiognomic communities

It has been not easy to visualize physiognomic communities on a representation. The use of the PCA offered the best ways to explore the internal structure and relationships of these communities. Since, the obtained β-diversity 23, 14 and 17 in the three phases of the study were greater than 6, overlaps of species communities are expected and the community visualization is possible using different ordination methods as presented at figure 69-71.

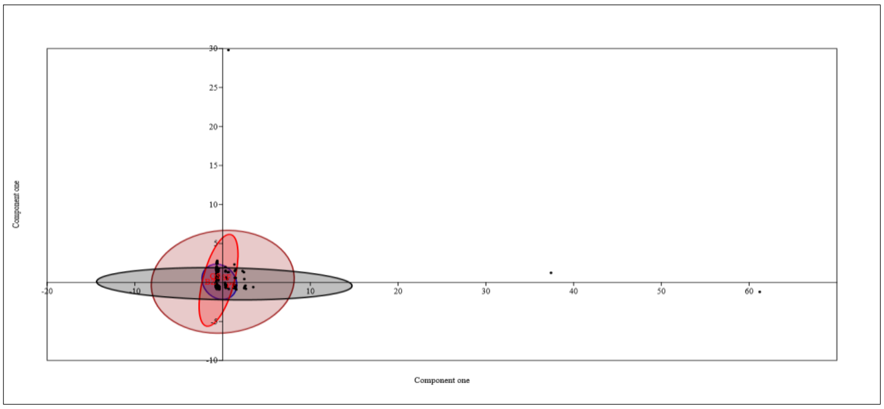


Figure 69: Initial PCA representation of communities

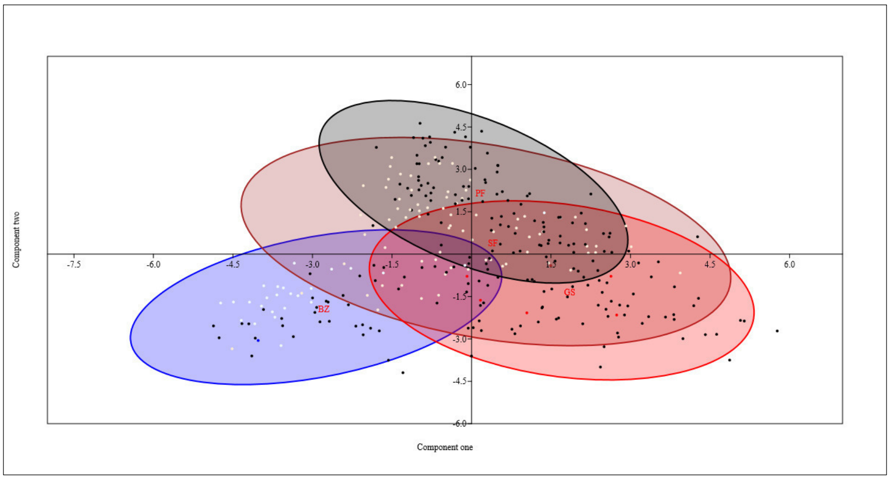


Figure 70: Intermediate PCA representation of communities for the period following the short rain season of 2019.

Different colors highlight communities understudy in the PCA analysis as follow:

Table 19: Forest types with their corresponding colors

Forest types	Colors
Buffer Zone	Blue
Secondary forest	Brown
Gasumo forest	Red
Primary forest	Black

The PCA presents a different plot of communities for the 3rd study period of the study.

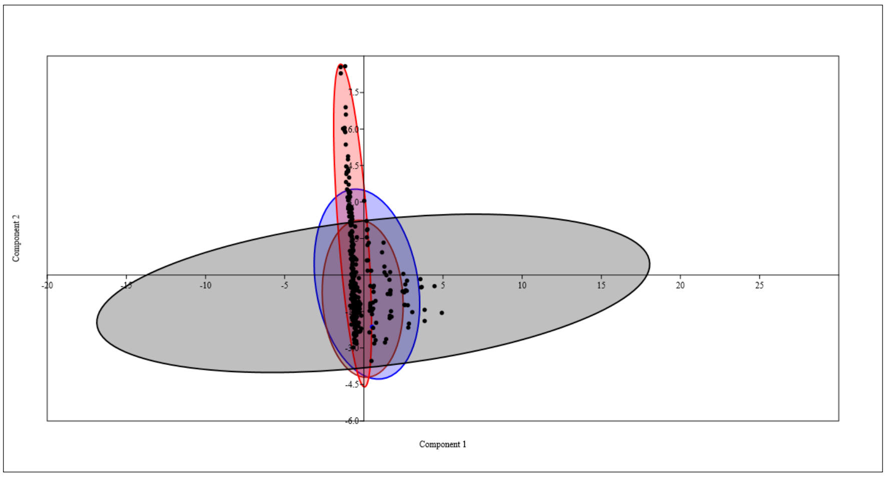


Figure 71: PCA representation of communities in the period following the long dry season 2020

The Figure 69 shows that all forest types had initially a big similarity with the secondary forest. For instance, Gasumo and the buffer zone were included within the secondary forest while the primary forest shared a big portion leaving a natural forest patch too small. Even though 23 distinct communities were identified, they were scarcely distributed around the secondary forest due to differences in species composition. A different figure is obtained for the secondary data set as presented at figure 69.

Fig.70 shows that the decrease in global beta-diversity caused the forest to show some signs of dissimilarities. This figure shows a prolific impact on forest species distributions. Although, it is still not easy to represent the four types of forests separately using PCA but there is a big change that has been made. It appeared that all forest types have a considerable similarity with the secondary encompassing large portions of Gasumo and the primary forest as indicated by the intersections of colors which indicates that there are samples sharing species in common and mostly distributed around the center of the two principal components. Although, the buffer zone has inverse relation with samples characteristics of the primary, secondary and Gasumo forests while maintaining similarity in few samples.

As revealed by beta diversity, there are 14 distinct assemblages currently available as portrayed by figure 70 and assured by the intersections of the four colors representing initial forest communities.

The global beta diversity for the 3rd term shows that there are seventeen overlapping communities available in the dataset due to similarities in species composition among forest types. As indicated by figure 71, the entire sample is almost secondary since plenty of samples and species are in secondary with a small part of Gasumo discarded from the secondary forest. Moreover, the primary forest is more associated to the fist Principal component while others relate to the second principal component.

The use of PCA in the ordination methods was justified by eigenvalues calculated and exposed at figure 72-75 successively.

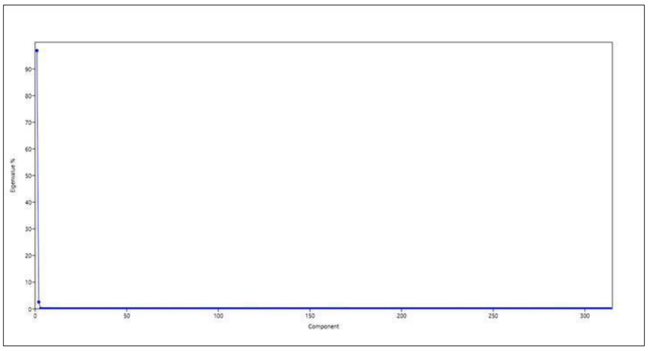


Figure 72: Initial Eigenvalue percentages for PCA analysis

The first eigenvalue explains 96.8% of the original data set while the second one explained 2.5% as shown by Fig and Broken-stick eigenvalues for data set indicate that the first two principal components (PC1 and PC2) resolutely captured more variance than expected by chance.

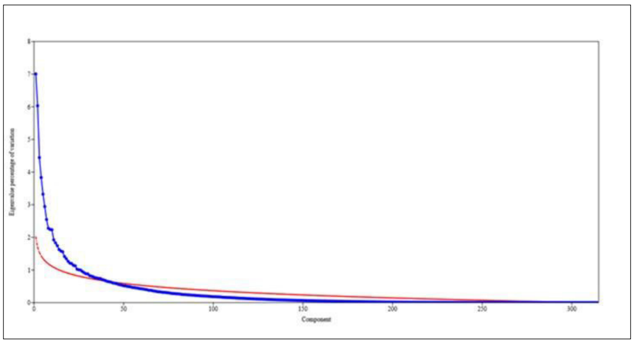


Figure 73: Eigenvalues for the intermediary dataset

This Figure shows that the first and the second component describes the data set at 70% and 60% respectively which prove their use in the ordination and classification of species with PCA approach.

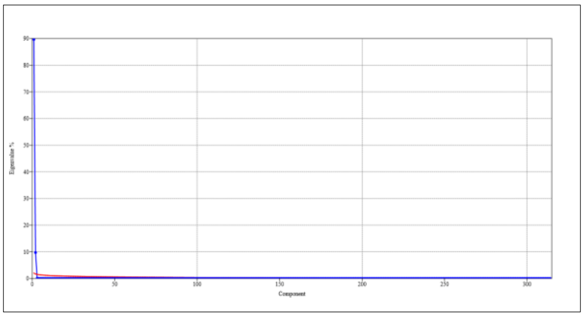


Figure 74: Eigenvalues for the final phase of the study

Figure 74 gives the descriptions of the components generated by principal component analysis with their percentages they do explain in the data. The red broken stick shows that the first component and the second component describe a great deal of the information in the data at a significant level that justifies their inclusion. It was assumed that the use of the first and the second component will capture plenty of the needed information in the data that allowed making a reliable and accurate analysis.

4.6 Factors of internal structure of forest landscape communities

The correspondence analysis graph has identified communities present in the entire sample as illustrated by the intersections of the ellipses colors, (BZ, SF, PF, and GS) respectively colored buffer zone, secondary, primary and Gasumo forest together with indicator species at presented at figure 75-77.

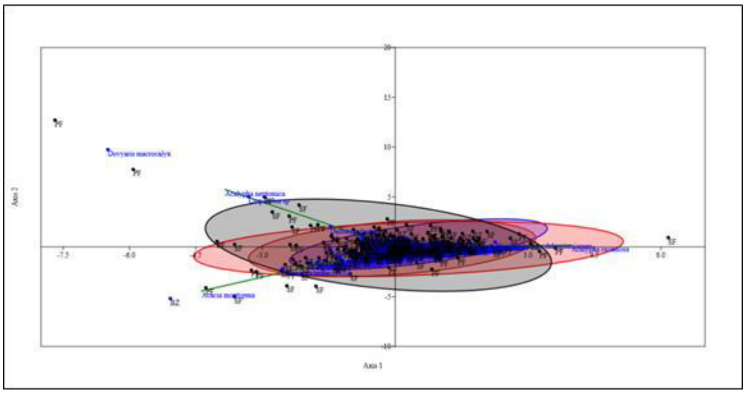


Figure 75: Initial forest structure and indicator species of community assemblages

Figure 75 give an insight of the forest at the initial phase of the study. *Acacia montigena* Brenan & Exell influenced negatively species distribution since its points downward with long vector magnitude that describes how dominantly it impacted the species population in secondary forest mostly where due to its life-form competitively disturbed the forest. This influence occurred to be realistic in all forest types; the presence of this type of species has led to the decrease in species around. *Acalypha neptunica* Müll. Arg. seems to be associated with the primary forest favoring some species but eliminating others since it occurs in the fourth quadrant. Many of the species are condensed in the center in a cloud, which implies the similarity in taxa composition among forest types and samples.

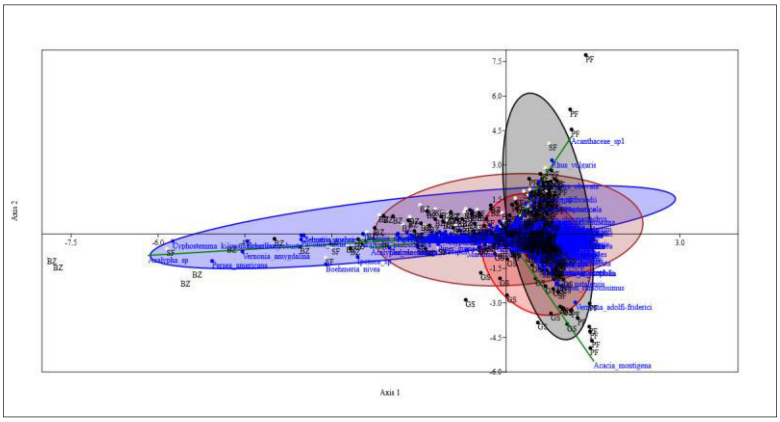


Figure 76: Forest structure and indicator species of community assemblages in CCA

In contrast, the second term of the study noted a massive change in the forest structure and community's distributions along with indicator species that influences assemblage criteria to change in properties and try to disclaim species dislocated that caused chaotic pastures. Figure 74 indicates that, even if *Acacia montigena* still has a negative impact on some species of the community because it is a forest destructive agent. *Acacia montigena* Brenan & Exell has reduced its impact on wide range of destructions associated with its presences. The forest has experienced a new architectural structure and restructured even though a big portion of the species has secondary characteristics. The buffer zone indicated its ability to be discarded from secondary forest with its big tail as well as the primary forest does together with others with interest of being separated from secondary forest as their communities assemblies tend not to be homogeneous with secondary forest.

The plot obtained has been different at the 3rd term of the study as displayed at fig 75.

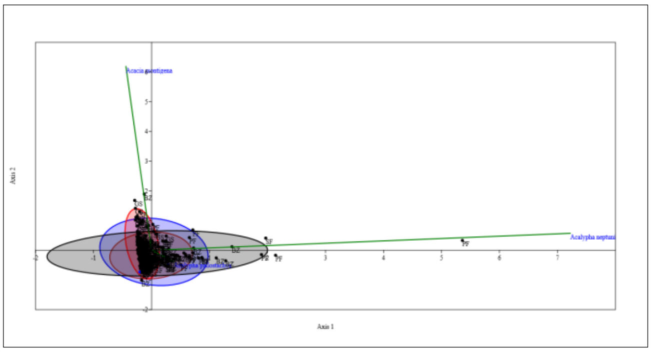


Figure 77: Indicator species using canonical correspondence analysis

Two main species contribute to the species distribution as figure 75 depicts and that there are the interactions of these two species with other species in all the forest types. *Acacia montigena* and *Acalypha neptunica* interact with other species across the forest with a significant magnitude in the primary forest. On the other hand, *Acacia montigena* is affecting the Secondary forest and Buffer zone as well as the Gasumo forest. The presence of *Acacia montigena* and *Acalypha neptunica* does not favor the presence of other species.

4.7. Influence of the disturbance level and cover percentage on forest communities

Environmental factors have been found to be the engine of the distribution of species in forest communities. The disturbance level and the cover percentage helped to identify patterns in species diversity and among communities. It appeared that the disturbance level increased with decrease of the canopy cover. This impacted the species abundance as well as the β-diversity in different physiognomic communities.

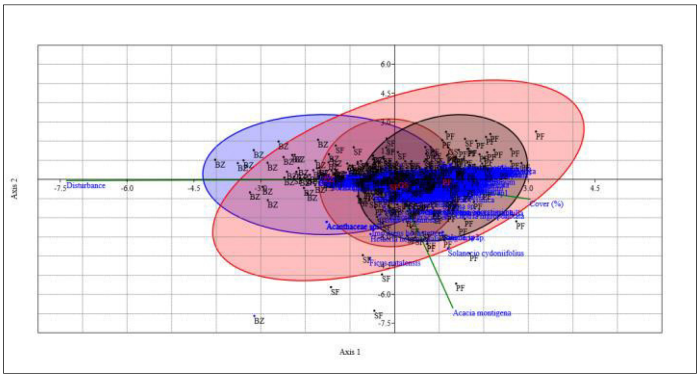


Figure 78: Initial impact of disturbance and cover percentages on the forest

Initially, the first axis of this canonical component analysis described 63.71 % of the original data while the second axis described the data by 36.29% and it appeared that the disturbance level has constantly affected the forest negatively as indicated by figure 78 in different plots of all the forests. The buffer zone indicated a high magnitude of the resulting vector of the disturbance levels which implies that it was initially highly disturbed together with some plots of secondary forest and primary forests. The disturbance level and the cover percentage showed a significant opposite correlation which indicated that a slight change of one of the two leads to the change in one way or the other. The increase in disturbance level has led to the decrease in cover permeates that also affected species distribution and their communities, too. In the diagram at figure 79, Gasumo and the secondary forest were found to be similar and closest with a largest cloud of species in common with a decrease of the cover percentage.

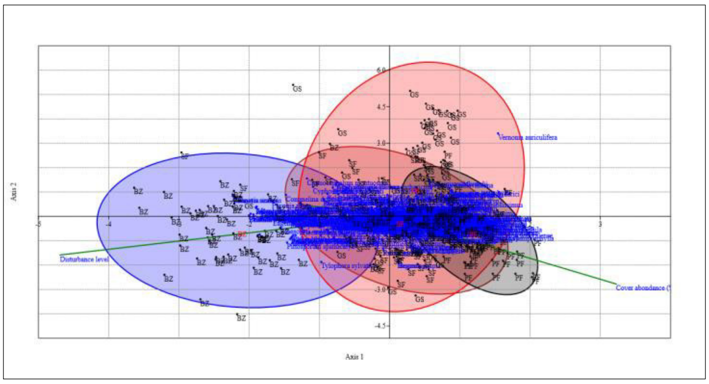


Figure 79: Change in the forest communities due to the disturbance and cover percentage

On the other hand, the primary forest maintained also a large cloud of species decreasing with the increase of the cover percentage while the buffer zone was discarded from other community assemblages with a decreased cloud of species with the increase of the level of the disturbance.

The intermediary state of the forest is shown by Figure above. As illustrated by the two figures 77 and 78, the distributions of the species is highly affected by the disturbance level and the reduction in canopy cover even though they are being interrupted on a considerable scale.

At fig 79, the canonical component analysis adequately described the data in a way that the first axis described 81.8% while the second axis described 18.19% of the original data when three environmental variables are considered. These environmental variables are plotted as correlations with site. Most of buffer zone sites correlate with the high level of disturbance and some sites at Gasumo and in secondary forest correlated with the low level of disturbance. As the figure depicts, the level of disturbance has still a negative impact in the buffer zone but has reduced the intensity when compare to its intensity portrayed by Figure 79 and the disturbance still has a small impact in other types of forest. The abundance cover is still shaping the species diversity negatively in primary forest as it is pointing down in black ellipse (Figure The species cloud remained dense in secondary forest separated from Gasumo previously overlapping. On the other hand, most of the sites in primary forest and few in secondary correlated with the cover percentage with minor changes in the initial data set as presented at figure 79.

These environmental variables always played a role in the distribution of the species at the final stage of the study as presented at figure 80.

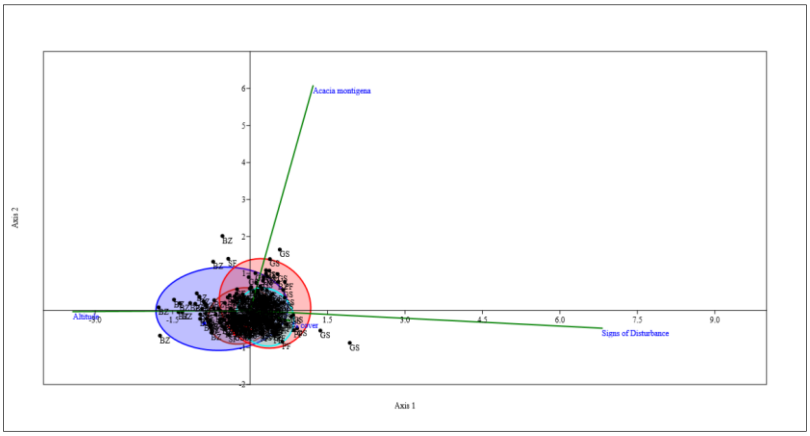


Figure 80: State of community structure at the final stage of the study

The figure 80 showed that the level of disturbance was responsible for species distribution and their relocation in different communities and the secondary, primary and Gasumo forests have been broadly impacted. On the other hand, there is a negative impact on the same forest by the percentage cover on a small magnitude. The altitude influenced also species abundance in buffer zone forest and primary forest and secondary forest. These justify how the slowing down of the level of the disturbance should be the priority in these particular forests that will lead to the stability of the entire forest. The density of the cloud at figure 80 showed that the studied forest types shared more similarities since there are closer each other with different drivers pulling a side the buffer while bringing together the secondary and primary forest absorbed within Gasumo in center of the cloud. This demonstrates how similar Gasumo and the primary forest are. Furthermore, *Acacia montigena* was found to have a negative impact on species abundance and distribution in primary, secondary and Gasumo forests.

4.8 Plant communities clusters

The global beta diversity was found high enough to hinder communities' distributions on ordinations as well as clustering methods where all the plots and species communities are quiet similar and hard to distinguish.

The plots represented at Figure 81, 83&85 show possible clusters to be drawn in the data. Since, beta diversities were found very high and divided the 315 plots into groups of high internal similarity with respect to species cover-abundance as also it was reflected on the dendrogram at 82-84&86.

The studied forest types as appeared on

Figure 82 showed that even though beta diversity almost 23, gave a global image of the forest with 23 distinct species communities at the initial time, however with high similarity. This also is similar to the information extracted from the Figure that showed that the forest was almost entirely the same as the species were condensed in secondary forest while a few plots were falling in primary.

At the intermediary phase of the study, the forest has experienced a change as it was discussed previously. The situation allowed visualizing the distribution of these plots in the forest types under consideration as depicted at figure 81,83, 85 where plots were randomly distributed but reshaped in replicated study phases and communities identified as possible forest physiognomies they belonged to. As it was shown using PCA that forest has shown dissimilarities at a given extend that permitted a small part of each forest to be discarded from others even though they still have a given similarity that allowed some of the plots to be included in different forest physiognomy sharing similarities in species composition.

It appeared that sites with analogous data content were grouped together and site members of phyiognomic groups close to each other confirmed the similarity in flora composition. Differences in species composition resulted in sub-group clusters under physiognomic groups. The joining of sites from different physiognomic groups resulted in clusters explaining same response of species to environmental gradients. Clusters allowed visualizing homogenous physiognomic communities within them and heterogeneous groups across different groups based on the abundance of species making natural groupings of similar characteristics.

The initial data set was found divided into six main clusters, themselves subdivided into several sub-clusters. The buffer zone was found more diverse joining different sites to other forest types and was mostly associated to high level of disturbance as presented at figure 81.

The secondary and primary forest sites of Cyamudongo were found more or less joined in different clusters and mostly influenced by the increase of the cover percentage and Gasumo study area even though, some sites were clustered mostly with the secondary forest was found far distant to other physiognomic groups. Homogenous clusters were mostly observed at Gasumo with more sites and the buffer zone with few sites dominated by exotic trees used for afforestation.

The initial phase showed a poor distinction of communities and their indicator species as seen on figure 82. Two main communities were separated in the initial data. *Elaeodendron buchananii*, *Pancovia golungensis*, *Peperomia tetraphylla*, *Justicia scandens*, *Clerodendrum buchananii*, *Solanum chrysotrichum*, *Hymenophyllum kuhnii*, *Trichomanes melanotrichum*, *Ixora burundensis*, *Dioscorea sp, Grewia sp* and *Asplenium mannii* had the greatest amplitude in first grouping of the initial data set. *Acalypha racemosa*, *Agelaea macrophylla, Grewia mildbraedii*, *Asplenium gemmiferum*, *Trilepisium madagascariense*, *Salacia erecta*, *Carapa grandiflora*, *Celtis gomphophylla*, *Macaranga kilimandscharica*, *Symphonia globulifera* and *Tectaria gemmifera* were found to be the most important indicators of the second cluster in the first data set as presented at figure 82 where most of sites studied were found similar to the secondary forest as described by the Canonical correspondence analysis as presented at figure 78.

In contrary to the initial data, two main clusters with a net separation were observed, the replicate allowed identifying 9 different species assemblage of different amplitudes as observed at figure 83 and 84. The number of distinct clusters increased at the intermediary stage of the study with almost all the sites at Gasumo joining together while sharing similarities with the secondary forest and dissimilar to the buffer zone and the primary forest. Homogenous clusters were drawn in primary, secondary forests as well as in buffer zones and the differentiation of communities became more apparent than in the initial phase of the stud with clusters subdivided into numerous subsets of small communities. Grouping of species communities of similar characteristics allowed identifying indicator species with their highest amplitude as described below:

The cluster group A is characterized by *Acanthopale confertiflora*, *Clerodendrum bukobense*, *Ficus sur*, *Maesa lanceolata* of high amplitude with the presence of shrubby trees and lianas such as *Harungana madagascariensis*, *Vitex doniana* and *Urera hypselodendron*.

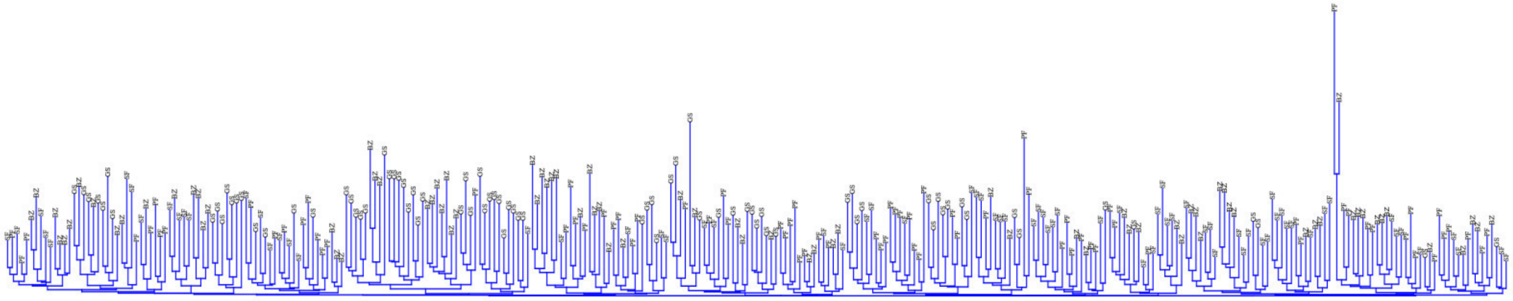


Figure 81: Cluster groups at the initial stage of the study in 2018

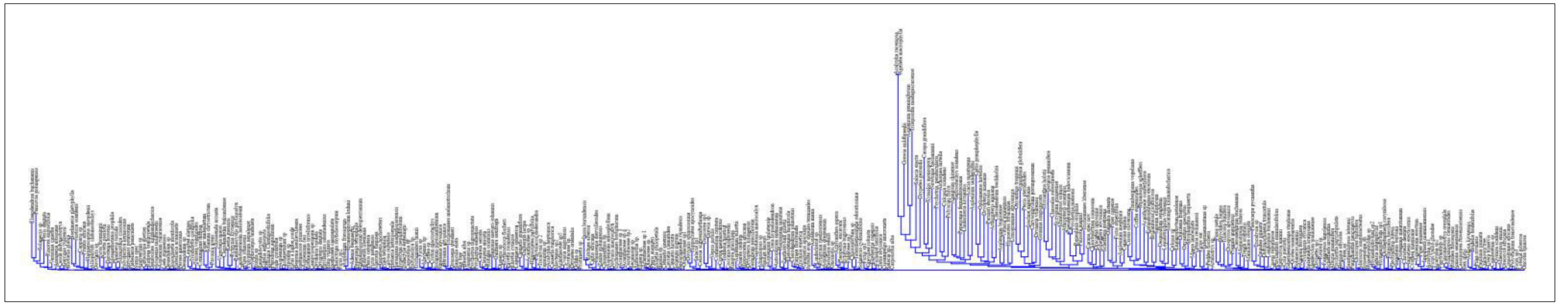


Figure 82: Initial indicator species of communities with Manhattan similarity measure (2018)

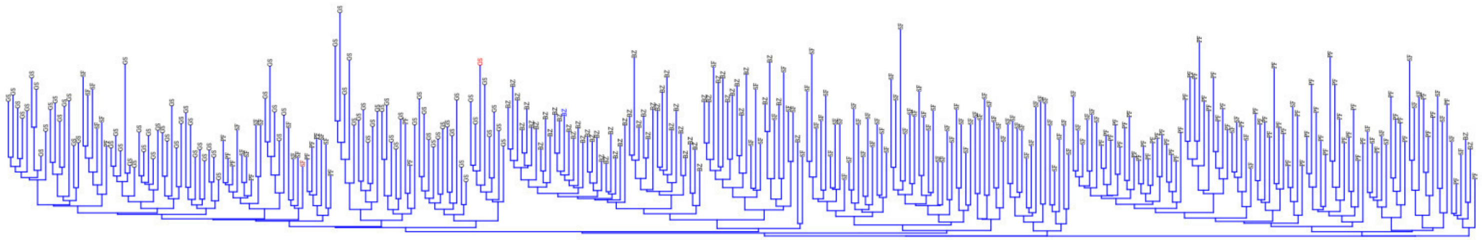


Figure 83: Cluster groups at the intermediary stage of the study in 2019

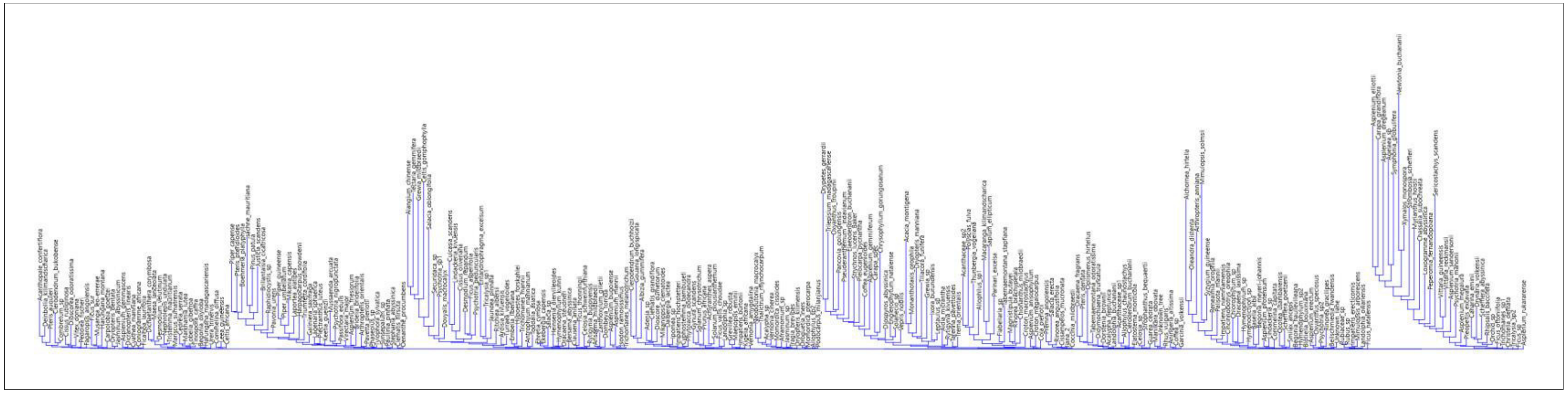


Figure 84: Intermediary indicator species of communities with Manhattan similarity measure (2019)

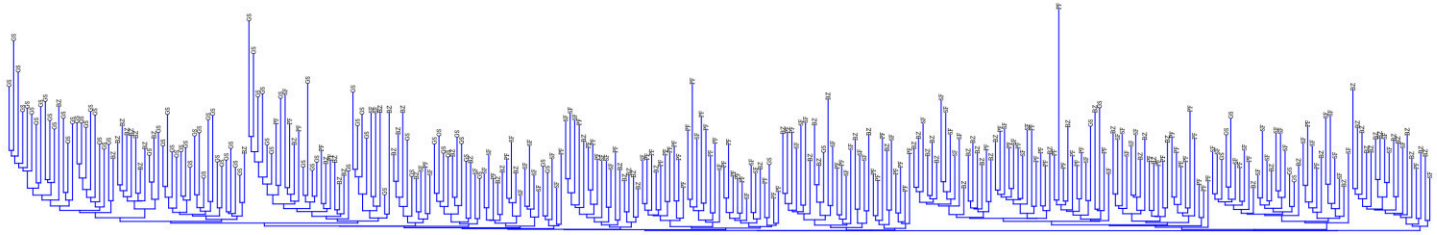


Figure 85: Cluster groups at the final stage of the study_2020

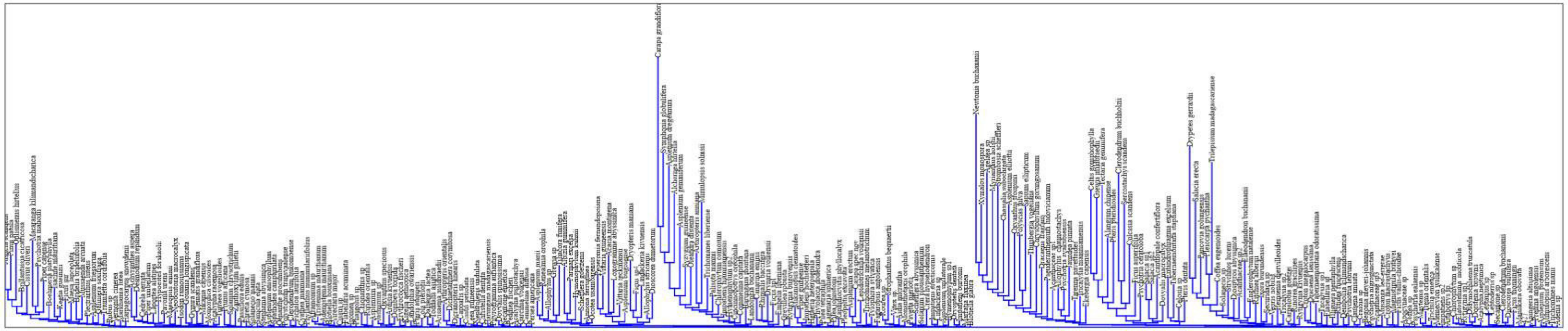


Figure 86: Final stage indicator species of plant communities with Manhattan Similarity (2020)

This community was found homogenous grouping together sites under disturbance at Gasumo due to killer lianas and *Acanthopale confertiflora competition.*

Pinus patula dominated the **cluster group B** associated to the buffer zone with a dense understorey made of *Isachne mauritiana*, *Pteris pteridioides*, *Piper capense*, *Justicia scandens* and *Brillantaisia cicatricosa*.

The **cluster group C** associated trees and climbers *Alangium chinense*, *Tectaria gemmifera*, *Celtis gomphophylla*, *Grewia mildbraedii, Salacia oblongifolia*, *Culcasia scandens* and *Entandrophragma excelsum*. The community seems to offer a good shade and humidity favorable to terrestrial Pteridophytes and epiphytes.

*Clerodendrum buchholzi*i, *Gouania longispicata* and *Albizia gummifera*, *Achyranthes aspera* dominated in the **cluster group D** with a diversity of heavy liana life-forms, a lack of canopy trees, or probably opened or disturbed.

The **cluster group E** was found to associate friendly canopy trees such as *Drypetes gerrardii*, *Trilepisium madagascariense, Oxyanthus troupinii*, *Elaeodendron buchananii*, *Chrysophyllum gorungosanum* firstly, and in another hand *Acacia montigena*, affected negatively the growth of tree species with the understory dominated by *Dryopteris manniana*.

The **cluster group F** was more associated to the secondary forest with the dominance of *Polyscias fulva*, *Macaranga kilimandscharica*, *Sapium ellipticum* and *Chionanthus mildbraedii*. The **cluster group G** associated shrubs and understorey such as *Dracaena fragrans*, *Pteris dentata*, *Oplismenus hirtellus* and *Strophanthus bequaertii* under a secondary forest with a weak canopy.

The **cluster group H** grouped sites of secondary forest dominated by *Alchornea hirtella* and *Mimulopsis solmsii* with enough shade and wet conditions to allow the occurrence climbers and epiphytes like, *Arthropteris anniana and Oleandra distenta*. The presence of climbers and epiphytes suggested the existence of host and support trees in the secondary forest. *Asplenium elliottii*, *Carapa grandiflora*, *Asplenium dregeanum*, *Agelaea sp., Symphonia globulifera and Newtonia buchananii* were found to have the highest amplitude in the **cluster group I**. The presence of *Asplenium elliottii* and *Asplenium dregeanum* suggested host trees of epiphytes and support of climbers in the communities under the primary forest canopy cover as observed at fig 81 and 82.

At the final phase of the study, the clustering show analysis shows more and net subdivisions between samples sites than in their corresponding species composition. More than 14 communities were observable in the study sites while species appeared to be clustered in 10 major communities where sites of different physiognomic community are clustered together based on similarity in species abundance composition among sites. It appeared that subdivisions of the 10 major clusters reflected homogeneity and heterogeneity in physiognomic compositions of sites. In addition, the distribution of the secondary forest physiognomic and the buffer zone among species clusters witnessed the past disturbance of the primary and Gasumo forests as observed at figure 83& 84.

In sites clustering, almost 9 groupings resulting from the classification separate more or less clearly and are depicted as follow:

The **cluster group A** is an association of Gasumo study area and the buffer zone: indicator species of this community are dominated by *Macaranga kilimandscharica, Psychotria mahonii, and Pinus patula* with a dense understorey of *Oplismenus hirtellus Mussaenda arcuata, Isachne mauritianum* and *Piper capense.*

The association **(cluster group B)** of some sites of study areas of Gasumo and the primary forest in one side and other sites Gasumo of study areas and the buffer zone at the other side characterize forests physiognomic groups where species show lower amplitude to be designed as indicator species. In this cluster, afforestation trees *Cedrela serrata, Maesopsis eminii* were found in the community and associated to a dense understorey dominated of *Achyranthes aspera, Desmodium repandum, Hypoestes forskahlei* and lianas due to the opening of the canopy. At the other hand, the community is affected competitive the competition of lianas such as *Gouania longispicata, Clematis grandiflora*, and *Gynura scandens* with the invasion of *Solanum chrysotrichum*. The presence of *Passiflora edulis* in the community is an indication of the past disturbance by human activities.

Cluster group C: An association of few sites of Gasumo study areas and the buffer zone at one hand and Gasumo and the secondary forest at the other hand formed a same community dominated by *Arthropteris orientalis* and *Dichaetanthera corymbosa* where the fruit tree *Persea americana* is occurring.

The **Cluster group D** associated the secondary forest, the primary forest and the buffer zone of Cyamudongo fragment forest. At one hand, *Albizia gummifera* and *Tiliacora funifera* and *Parinari excelsa, Grewia sp*. are the most indicator species while the other side is influenced by *Acacia montigena* found to have the highest amplitude with a behavior that inhibited the growth of forest trees. In both cases, the tree canopy offered a shade favorable to the occurrence Pteridophytes and mostly epiphytes such *Asplenium mannii, Hymenophyllum kuhnii, Vittaria guineensis, Loxogramme abyssinica, Vittaria reekmansii, Asplenium bugoiense* and *Dryopteris manniana.*

The cluster group E associates some sites of the secondary forest and the buffer zone with a weak association to the primary forest and indicators of highest amplitude such as *Carapa grandiflora, Symphonia globulifera,* and *Alchornea hirtella*. The community seems to favor epiphytes such as epiphytes due to prevailing conditions with humidity and the understorey dominated by *Mimulopsis solmsii*.

The cluster group F is a homogenous primary forest with a weak association to the secondary forest was found to be a cluster dominated by trees such as *Sapium ellipticum, Newtonia buchananii, Xymalos monospora, Myrianthus holstii, Strombosia scheffleri, Chrysophyllum gorungosanum, Sapium ellipticum* but also with signs of disturbance dominated by heavy lianas such *Agelaea sp.*

The cluster group G is a larger heterogeneous association of the buffer zone, secondary forest and the primary forest with internal rearrangement and a very poor relationship with Gasumo where indicator species with the highest amplitude were found to be *Celtis gomphophylla, Grewia mildbraedii, Clerodendrum buchholzii,* and *Alangium chinense* and invaded by the liana, most tree killer *Sericostachys scandens*.

In the **cluster group H**, the association of sites from the secondary forest, some sites of the study area of Gasumo and the primary forest formed a community with *Drypetes gerardii, Trilepisium madagascariense,* and *Elaeodendron buchananii* as indicator species where lianas benefit from high canopy trees.

The **cluster group I** is made more or less made of homogenous buffer zone community where species show lower amplitude to be designed as indicator species not dominated by trees. To summarize, in the period of the study, dynamism was found in clusters of studied sites as well as in their corresponding plant communities. Physiognomic classifications of Cyamudongo and the study sites at Gasumo were found with close relationship at the initial phase of the study with non-clear and net separation between plant species assemblages due to absence of dominant species to be considered as indicator species with important magnitude. Furthermore, lower level clusters were found overlapping with a low number of species associations. Clusters of sites at the intermediate phase of the study showed separated almost all physiognomic communities in distinct groups. At one side, physionomic communities of Cyamudongo where the primary forest was found more close to the secondary forest than the buffer zone and at other hand distanced from the study area of Gasumo in the main Nyungwe forest where some sites of the secondary forest widespread in the sub-clusters of Gasumo forest. Species cluster showed spatial aggregation corresponding to sub-clusters of sites in each physiognomic community.

Even though, at the final phase the same architecture remained between Cyamudongo and Gasumo studied area of the main block of Nyungwe National Park, some sites of the primary forest of Cyamudongo were found more closely related the heterogeneous sub-clusters of Gasumo with some level of disturbance similar to the secondary forest and the buffer zone of Cyamudongo. Meanwhile, there are sites in primary forest, secondary and buffer zone are clustered together due to similarities in species composition and others close to Gasumo study area with homogeneous cluster of sites discarded to this general pattern.

4.9 Landscape patterns of species richness in Cyamudongo and Gasumo

4.9.1 Statistical differences among physiognomic landscapes of Cyamudongo and Gasumo

The multivariate analysis of the variance showed that response variables displayed significant statistical differences in forest types since the global p-value is equal to 2.595e-12 as presented by the output of the MANOVA test at table 20.

Table 20: MANOVA output at α=0.05

	Df	Pillai	approx F num	Df	den Df	Pr (>F)
Forest types	3	0.22766	8.513	9	933	2.60E-12
Residuals	311					

Table 20 shows that the Pr (>F) from the table above is less than α. This implied to reject to reject the null hypothesis and to take the alternative hypothesis and that there is a significant statistical difference in the species occurrences during the three phases of independent data collection between the forest types and in three different periods.

4.9.2 Normality distribution of species occurrence

The normality distribution of the dependent variable which is technically the normality of the residuals in each group has been confirmed in the one-way ANOVA. Fig 86 & 87 for the initial phase in 2018, fig 85 & 86 for the intermediate phase and fig 87& 88 for the final phase evidenced the normal distribution.

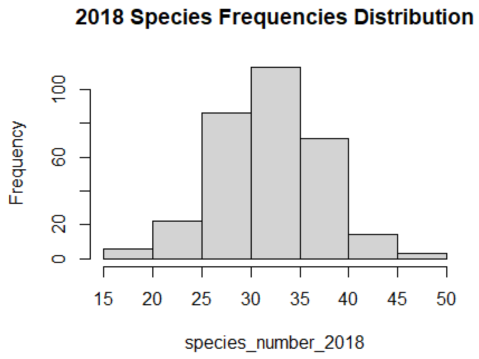


Figure 87: Species histogram in 2018

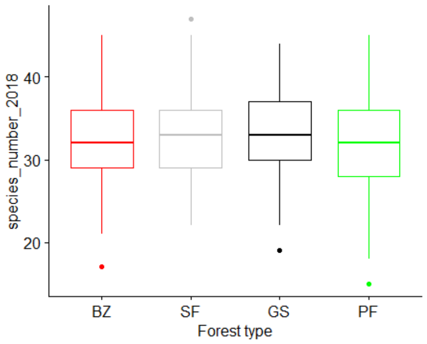


Figure 88: Species histogram in 2018

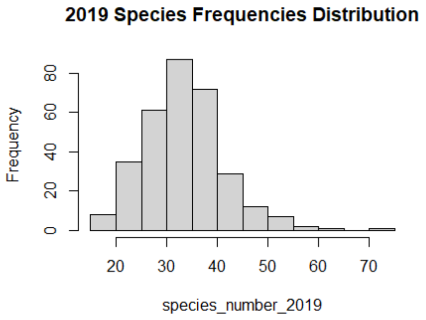


Figure 89: Species histogram in 2019

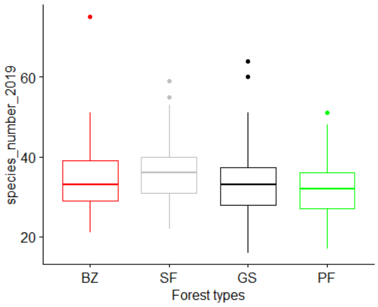


Figure 90: Species histogram in 2019

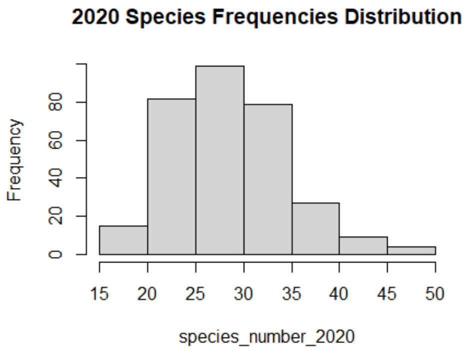


Figure 91: Species histogram in 2020

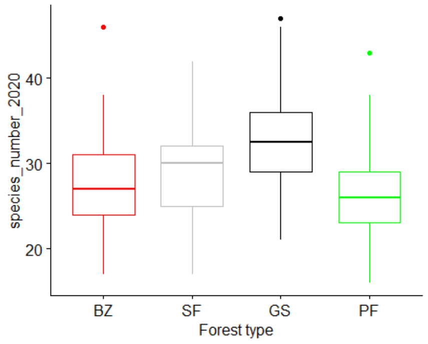


Figure 92: Species histogram in 2020

Figures 87, 89, 91 indicate species frequencies in the plots of the data collected in 2018, 2019, 2020 respectively and also express the validation of the normality assumption since the histograms illustrate that data are symmetrically distributed around the mean with no weird tail or peak. Figures 88, 90 & 92 attributed a large number of species occurrence to Gasumo, SF; and GS respectively in 2018, 2019, and 2020 since their boxes are a bit leveled compare to the others. At the initial phase, the BZ, GS, and PF each have one outlier marked by the dots. The most startling information is that, the four forest types encompass almost the same volume of species occurrence as indicated by their accumulation in their corresponding boxes. Even though, at the intermediate phase, the secondary forest has a large number of species occurrences since its box is a bit leveled compare to others and the outliers marked by the black dots but all the forest types on average have the same amount of species accumulation as indicated by their boxes. The groups that are considered reveal useful results not only for the description but also for the analysis of the variance. The final phase point out that Gasumo at this time comprise a high number of species occurrences than other forest types with one outlier marked by a black dot. In contrast, the primary forest owns a small number of species occurrences compared to others. Generally, there are three outliers that are above the normal differences from the mean as depicted on the exemplary graph by the dots on the upper level.

4.9.3 Statistics of species distribution among forest types in different phases

The means of species occurrence and their standard deviation are presented in tables.

Table 21: Statistics of 2018 among forest types

FT	count	mean	sd
BZ	78	32.3	5.35
GS	80	32.7	4.74
PF	79	31.7	6.05
SF	78	33	5.44

Table 22: Statistics of 2019 among the forest types

FT	count	mean	sd
BZ	78	34	8.11
GS	80	33.6	8.34
PF	79	32	7.44
SF	78	36.3	7.86

Table 23: Statistics of 2020 among forest types

Forest types	count	mean	Sd
BZ	78	27.7	5.27
GS	80	32.6	5.96
PF	79	26.1	4.82
SF	78	29.3	5.13

The groups reveal useful results not only for the description but also for the analysis of the variance and point out the statistical variation in species occurrences among the groups. In all phases, mean averages showed that Gasumo and the secondary forest were richer in species than other physiognomic communities.

4.9.5 Species occurrence in separate phases

With a level of significance (α=0.05), the outputs of the ANOVA are presented in table 24, 25, 26.

Table 24: ANOVA output of the initial phase (2018)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
FT	3	73	24.25	0.828	0.479
Residuals	311	9109	29.29		

Table 25: ANOVA output of intermediate phase (2019)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
FT	3	727	242.37	3.838	0.0101
Residuals	311	19642	63.16		

Table 26: ANOVA output of the final phase (2020)

	Df	Sum Sq	Mean S	F value	Pr (>F)
FT	3	1855	618.2	21.9	6.85e-13
Residuals	311	8781	28.2		

Table 24 shows that the p-value is greater than α (0.05). This implies that there is no statistically significant difference between the mean of the forest types. On this case, there is no need of further investigation since there is no difference at the initial phase of the study in 2018.

At the other hand, the p-value (0.01) in the table 24 is less that the level of significance and the ANOVA table 26 indicating the p-value almost zero and of course less than α, imply a significant statistical difference among at least two of the forest types for both cases. These statistical results did not tell which forest types are significantly different or the ones that show no difference.

4.9.6 Dissimilarity or similarity among pairs of physiognomic communities

The Tukey test unraveled differences and similarities are presented in the table 27 and 28 respectively for the year 2019 and 2020.

Table 27: Tukey pairwise comparison of means at 95% confidence level for 2019

Forest types	diff	lwr	upr	p adj
GS-BZ	-0.4371914	-36.728.065	2.798.424	0.9853806
PF-BZ	-20.373.496	-52.832.512	1.208.552	0.3681299
SF-BZ	22.686.420	-10.207.875	5.558.071	0.2842214
PF-GS	-16.001.582	-48.560.611	1.655.745	0.5831053
SF-GS	27.058.333	-0.5934654	6.005.132	0.1495146
SF-PF	35.637.628	0.9966042	7.615.379	0.0048234

The results in the table 27 show that the adjusted p-value which is less than α indicates that SF and PF are statistically different in 2019 making two different clusters. The means that the pairs of PF-BZ, SF-BZ, PF-GS, SF-GS, SF-BZ, GS and BZ, are statistically identical since their adjusted p-values are greater than α and should explain the inclusion of the members of the pair in same cluster due to similarities. These similarities should be useful to explain sub-clusters with mixed sites, their species composition and the unicity of the primary and secondary forest sites.

Table 18: Tukey pairwise comparison of means at 95% confidence level for 2020

Forest types	diff	lwr	upr	p adj
GS-BZ	4.945.833	27.824.497	71.092.170	0.0000001
PF-BZ	-1.565.401	-37.356.623	0.6048606	0.5580007
SF-BZ	1.600.000	-0.5993648	37.993.648	0.2391633
PF-GS	-6.511.234	-86.881.826	-43.342.858	0.0000000
SF-GS	-3.345.833	-55.517.969	-11.398.698	0.0006335
SF-PF	3.165.401	0.9526919	53.781.098	0.0014750

The same Tukey test results of table 28 show that, there is a significant statistical difference in between GS-BZ, PF-GS, SF-GS, and SF-PF since their adjusted p-values are less that the alpha. However, the pair SF-BZ shows no statistical difference since its adjusted p-value is greater than α. This pairwise comparison helped to understand clusters segregation with some sites of each physiognomic community, similarities in species composition between the buffer zone and the secondary forest of Cyamudongo.

4.9.7 Validity of results

The statistical results have proven their validity since; errors follow the normal distribution as depicted on figures 93, 94, 95.

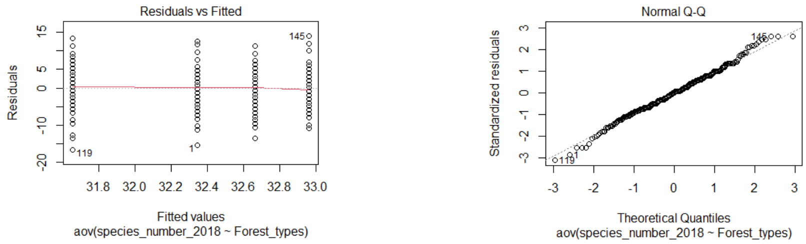


Figure 93: Validity of results of the initial phase of 2018

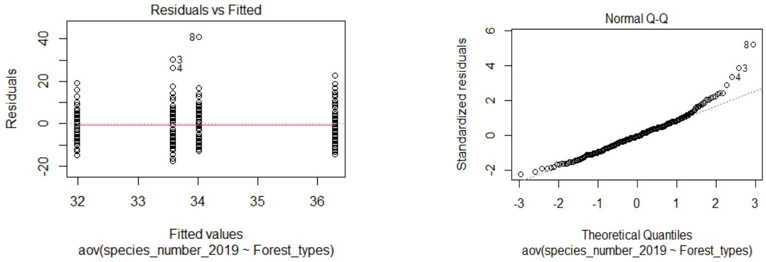


Figure 94: Validity of results of the intermediate of 2019

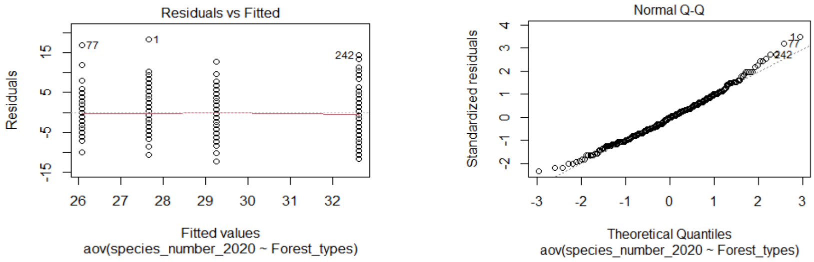


Figure 95: Validity of results of the final phase of 2020

The figure 93, 94, 95 of normal Q-Q showed that the fitted lines in the residuals did not depart from normality since lines fitted very well one to one relation which justifies that results have been statistically correct to validate the conclusion and portrayed the validity of differences or similarity observed previously.

It appeared also that the residuals are normally distributed since the red line is pointing to the mean zero and there is not departure from the normality. The observed distribution of the residuals is the same as the normal distribution curve, which implies that the plotted points follow a 1-1 relationship. That is, the displayed straight line suggests that the residuals follow the normal distribution. Since there is no clear increase or decrease in the edge of points in the scale-location plot; it implies that the constant variance assumption is not violated.

4.10 Influence of disturbance and cover on species occurrence

The Two way ANOVA using R programming language and produced figures 96, 97 & 98 for the three phases of the study to evaluate if the level of disturbance or the canopy cover were significantly causal agent of differences or if their interaction caused differences among forest types. Keys for canopy cover classification: HC = High cover; MiC =Middle cover; MoC = Moderate cover; LC = Low cover while to classify disturbance categories, HD = High Disturbed; CH = Changed Habitant; MD = Moderate Disturbance.

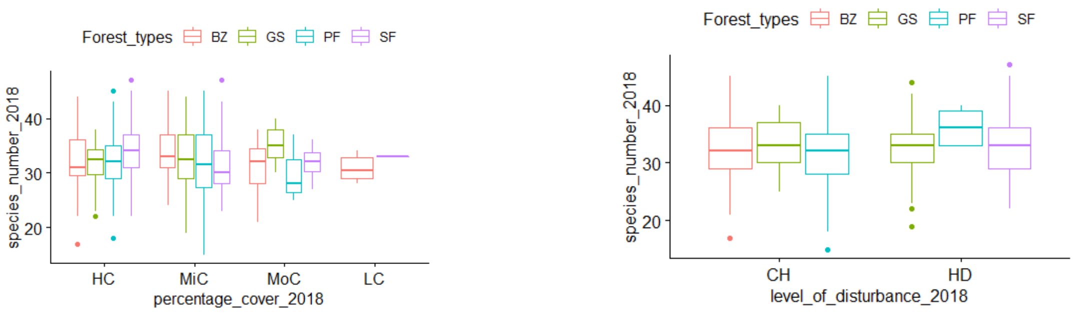


Figure 96: Effect of canopy cover and level of disturbance at the initial phase

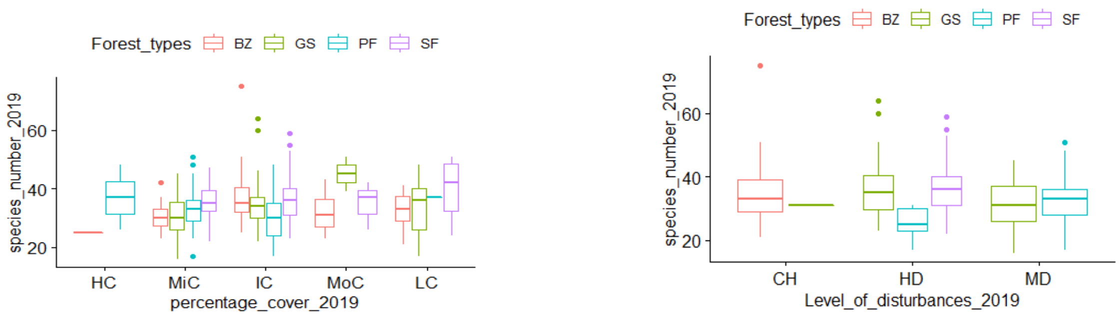


Figure 97: Effect of canopy cover and level of disturbance at the intermediate phase

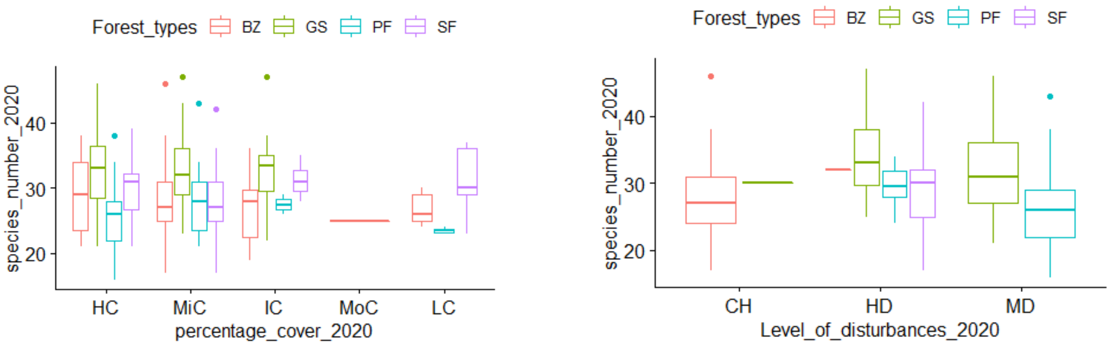


Figure 98: Effect of canopy cover and level of disturbance at the final phase

The plot at figure 96 showed that at the initial phase of the study, the occurrences of species was high in middle canopy cover for all landscapes but with the lowest occurrence in secondary forest. In a higher canopy cover, the high occurrence of species was found in buffer zone and the secondary forest and the low occurrence was observed in primary forest and Gasumo. Moreover, the general trend showed that there was a positive relationship between the species occurrence and the canopy cover in all landscapes while the low canopy cover favored the buffer zone and the secondary forest.

At the other hand, the level of disturbance was found to be a factor of species occurrence in physiognomic groups where the increased canopy impacted negatively the species occurrence in the buffer zone while positively associated to species occurrence at Gasumo and the secondary and primary forest of Cyamudongo.

In addition, the occurrence of species was found high in changed habitat for the buffer zone than the primary and Gasumo studied area while higher species occurrence dominated the highly disturbed of the primary forest. At the intermediate phase shown at figure 97, the occurrence of species was found to be associated negatively the canopy cover in general of the buffer zone, the secondary forest of Cyamudongo and the study area of Gasumo in Nyungwe main block and the reduction of the disturbance correlated positively with the increase in species occurrence in the primary forest of Cyamudongo, and at Gasumo studied area. The primary forest has a huge number of the species occurrence in higher the canopy cover while in lower ones, the community is not present. In the middle percentage and intermediate percentage cover, the species occurrence is almost equally distributed while in a moderate and lower cover there is no effect of disturbance.

At the final phase shown at figure 98, the interaction between the percentage cover and the level of disturbance has impacted for sure the species occurrence and the concentration in the forest types. The figure indicated no species concentrated in the moderate cover of percentage. Instead they are concentrated in the high cover, middle and intermediate cover.

Significance level using Two Ways ANOVA

To see the effect of the cover percentage and the level of the disturbance on the species occurrence, Two Way ANOVA was used and tried to relate what is on boxplot presented at figure 96, 97 and 98 and tables 29, 30 and 31.

Table 29: Two Ways ANOVA for 2018

	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Canopy cover_2018	3	25	8.31	0.286	0.835
Disturbance	2	121	60.4	2.079	0.127
Cover_2018-disturbance	5	204	40.81	1.404	0.222
Residuals	300	8717	29.06		

Table 30: Two Ways ANOVA for 2019

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Canopy cover_2019	4	217	54.2	0.89	0.470225
Disturbance	2	970	484.9	7.964	0.000426
Cover_2019-Disturbance	6	795	132.4	2.175	0.045292
Residuals	302	18388	60.9		

Table 31: Two Ways ANOVA for 2020

	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Canopy cover_2020	4	60	15	0.48	0.751
Disturbance	2	800	400	12.795	4.63E-06
cover_2020:disturbance	6	335	55.9	1.787	0.101
Residuals	302	9440	31.3		

In general, the percentage cover alone, the disturbance level alone, and their interaction contributed to the similarities of the forest types under consideration since their p-values are quite far from the alpha-value 0.05. In particular table 29 showed that the canopy cover whose p-values 0.835 far greater than the alpha value is trivial the causal agent of similarity. The adoption of the alternative hypothesis supports the idea that whenever this factor did not play a prominent role in the differences in the forest types, then it has contributed to their similarities.

At the intermediate phase, the cover of percentage is not significant since its p-value is greater than α, to means that the percentage cover did not contribute to the means difference of the four forest types. On the other hand, the disturbance level contributed a lot since its p-value is far small than the alpha. The interaction between the cover of percentage and the level of disturbance whose p-value is 0.045292 indicates the statistical significance to cause the species occurrences to mean difference. Both are the factors that impacted and contributed to the mean differences in the four forest types. In the same way, at the final phase of the study as presented at table 31, the level of the canopy did not contribute to the species occurrence in the four forest types since it is not statistically significant as its p-value is very high compared to the alpha. But the effect of the disturbances in the species occurrence is significant since its p-value is small to the p-value. Their interaction is not significant as their p-value is greater than the alpha value. The factor that contributed to the difference here is just disturbance level.

4.11 Life-forms distribution among physiognomic communities

In the three phases of the study, the total records of vascular plants reached 32.495 unequally distributed among vegetation sampling periods and life forms of different plant species recorded in different physiognomic communities as presented at table 32, 33, 34 and means percentages at table 35.

Table 32: initial total life forms distribution

FT	PH (%)	CH (%)	H %)	TH (%)	G (%)	E (%)
BZ1	71.07	2.14	2.32	10.18	10.85	3.44
SF1	74.08	0.18	0.85	4.77	9.59	10.53
PF1	81.59	0.07	0.32	4.05	7.99	5.98
GS1	71.14	0.07	3.86	4.21	5.15	15.57

Table 33: Intermediate distribution of life forms

FT	PH (%)	CH (%)	H (%)	TH (%)	G (%)	E (%)
BZ2	69.88	2.04	1.27	6.87	15.24	4.70
SF2	73.61	0.32	1.09	2.53	11.72	10.73
PF2	85.68	0.11	0.49	1.54	7.44	4.74
GS2	66.41	0.15	0.36	3.56	15.01	14.50

Table 34: Distribution of life forms at the final phase

FT	PH (%)	CH (%)	H (%)	TH (%)	G (%)	E (%)
BZ3	67.85	1.84	1.17	7.18	15.99	5.97
SF3	60.22	0.39	1.62	4.42	17.64	15.71
PF3	86.75	0.12	0.51	1.61	7.18	3.84
GS3	45.87	0.26	0.52	9.72	21.58	22.05

Keys: FT = Forest types, PH = Phanerophytes (MGPH = Megaphanerophytes, MSPH = Mesophanerophytes, MPH = Microphanerophytes, NPH = Nanophanerophytes); H = Hemicryptophytes; TH = Therophytes; G =Geophytes; E = Epiphytes.

The table 35 presents the mean percentages of life forms for the three phases of the vegetation sampling in physiognomic communities.

Table 35: Comparative account of life forms means of physiognomic communities

FT	PH (%)	CH (%)	H (%)	TH (%)	G (%)	E (%)
BZ	69.60	2.01	1.59	8.08	14.03	4.70
SF	69.30	0.30	1.18	3.91	12.99	12.32
PF	84.67	0.10	0.44	2.40	7.54	4.85
GS	61.14	0.16	1.58	5.83	13.91	17.37

In general, plant species records at the initial, the intermediate and the final phase of the study were dominated by Phanerophytes which included Megaphanerophytes, Mesophanerophytes, Microphanerophytes and Nanophanerophytes followed by Geophytes. In the three phases of the study, life forms changed from one phase to other and the primary forest landscape dominated others landscapes with respectively 81.59%, 85.68%, 86.75% of total Phanerophytes for the initial, intermediate and final phase of vegetation sampling.

Means values of life forms presented at table 35 show that the buffer zone was close to the secondary forest in Phanerophytes while Gasumo was the lowest.

4.11.1 Raunkiaer's life-forms spectra

The following figures present Raunkiaer's spectra of the three phases of the study (figure. 99, 100, 101).

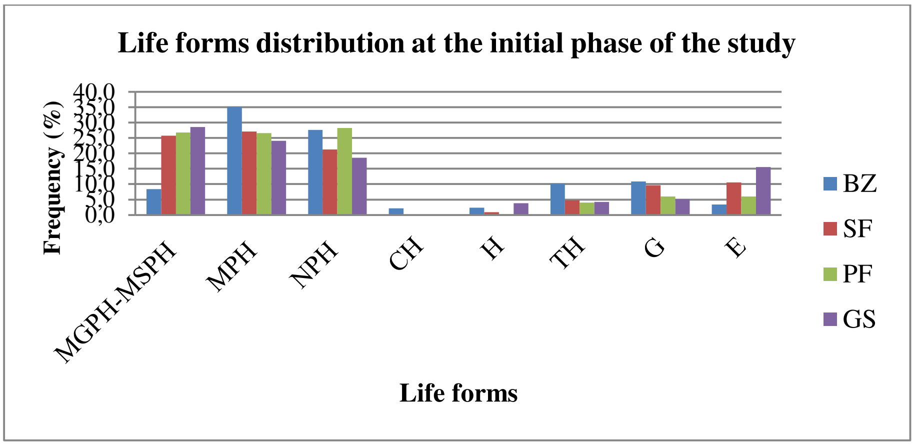


Figure 99: Initial Biological spectrum of landscapes of Cyamudongo and Gasumo

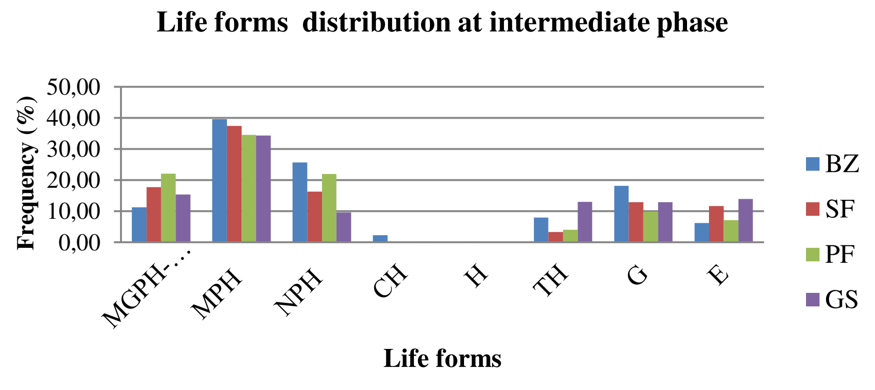


Figure 100: Intermediate biological spectrum of landscapes of Cyamudongo and Gasumo

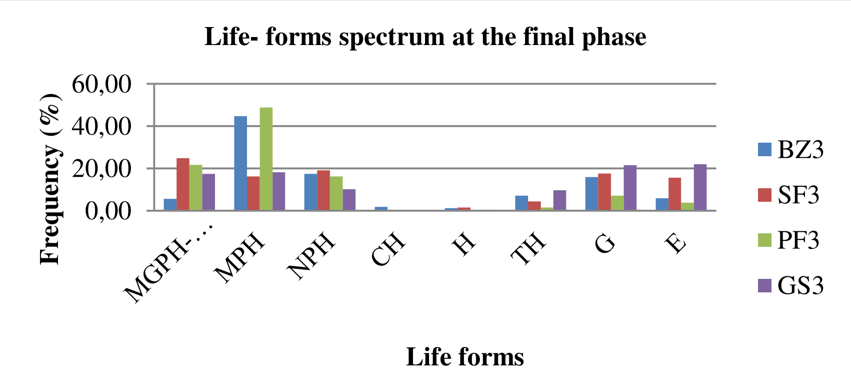


Figure 101: Final phase biological spectrum of landscapes of Cyamudongo and Gasumo

Figure 99 and 100 show almost similar trends in life forms distribution of the initial and intermediate phases of the study with a dominance of Phanerophytes. Higher biological forms of mature trees at Gasumo dominated slightly the spectrum of the primary forest almost at same level as the secondary forest at the initial phase. But, Megaphanerophytes together with Mesophanerophytes were found important in primary forest physiognomy than in other communities. Microphanerophytes or saplings and Nanophanerophytes or seedlings responded to a same trend with dominance in buffer zone followed by the secondary forest at the initial phase and the primary forest at the intermediate phase. Lower life forms are dominated by geophytes and epiphytes. Geophytes were more favored in the buffer zone and the secondary forest while Gasumo and the secondary forest were found more suitable to epiphytes.

At the other hand, Megaphanerophytes and Mesophanerophytes were found to dominate the secondary forest followed by the primary forest while saplings or Microphanerophytes dominated the primary forest and the buffer zone. Furthermore, lower biological life forms such as geophytes and epiphytes dominated respectively Gasumo and the secondary forest as presented at figure 101. In general, the recorded vascular plants belonged mostly to Phanerophytes distinguished into Megaphanerophytes, Mesophanerophytes, Microphanerophytes and Nanophanerophytes and to Geophytes at all the phases of the study. The trend of life forms spectra was found almost similar at the initial phase and the intermediate phases of the study with a decreased frequency of recorded plant species. At the other hand, a difference in life forms spectrum occurred at the final phase with a reduction of Microphanerophytes in the secondary forest and Gasumo.

4.11.2 Similarity of physiognomic communities on the basis of life forms

Life forms allowed to assess relationship between physiognomic communities in the three phases of the study as presented at figure 102.

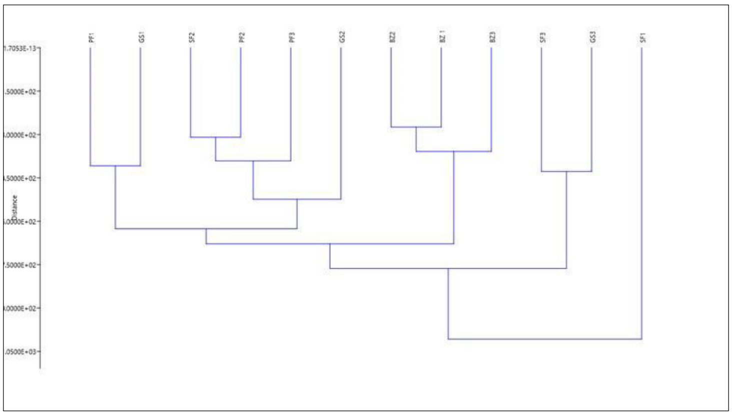


Figure 102: Classification of forest types based on species life forms

The analysis of life forms showed that all the three phases of the buffer zone were close to each other. At the intermediate phase, the primary forest was found close to the secondary forest at one side and close to Gasumo at the other side. Furthermore, the secondary forest was found close to Gasumo at the final stage of the study while Gasumo was discarded from other communities at the initial phase. The hierarchical clustering of the total life forms using "Two way UPGMA" allowed to identify 5 clusters as presented at figure 102 as follow:

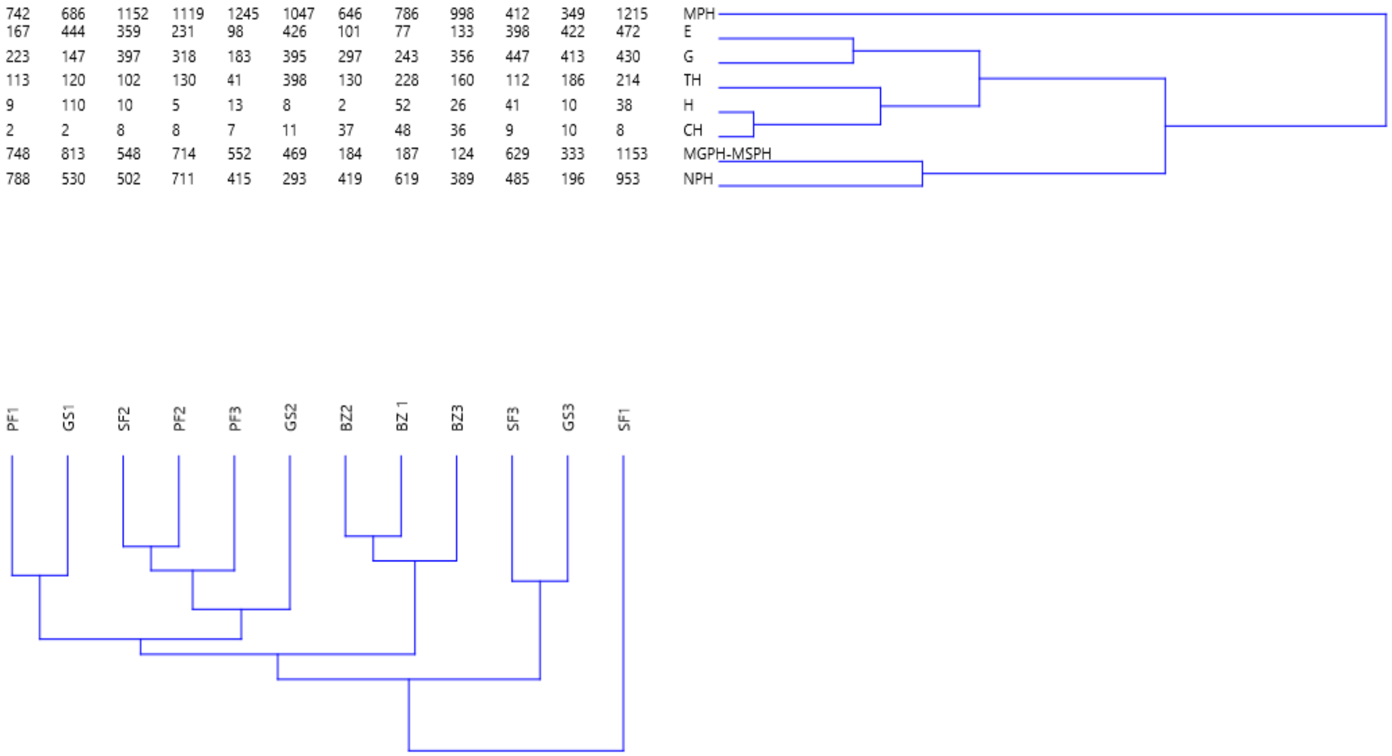
SF1 cluster group designed a community with almost equally high quantities of high canopy and young trees allowing the growth and development of geophytes and epiphytes with a less opened canopy.

SF3- GS3 cluster group designed a community which groups together 38.40 % and 20.33 % of the total higher life forms (Megaphanerophytes and Mesophanerophytes) and 13.72 % and 11.62% respectively for the secondary forest and Gasumo at the final phase of the research. This means that at this level the secondary forest was more or less similar to Gasumo. This community allowed the occurrence of lower life forms where conditions favor epiphytes and geophytes growth. BZ1-2-3 cluster group designed a cluster group with the lowest percentage of mature trees (higher Phanerophytes) mostly of exotic trees used for afforestation such as *Pinus patula, Maesopsis eminii, and Grevillea robusta* making 6.45%, 11.60 % and 7% of the total higher Phanerophytes recorded respectively at different phases of the survey. This subgroup community included 22. 2 %, 21 % and 30. 8 % of lowest categories of Phanerophytes which shows that the community is under regeneration and allows the growth of lower life forms such as Chamaephytes, Hemicryptophytes and Therophytes with a decrease in number of epiphytes. The decrease of the occurrence of epiphytes is likely to be impaired to the decrease of host trees and the canopy trees that facilitate penetrance of radiations with development of the understorey.

SF2-PF2-PF3-GS2 cluster group associated life forms of the secondary forest (SF2) and the primary forest intermediate and final phases and the intermediate phase of Gasumo. The similarity of the life forms may due to the nature of disturbance affecting these forest physiognomies. This community was characterized by almost close ratios of higher Phanerophytes and microphanerophytes. It seems to be disturbed with a good level of regeneration. Ratios were 34.6%, 24.4%; 29.2 % of higher canopy trees of Megaphanerophytes-Mesophanerophytes respectively and 30 %; 29% and 22% of Microphanerophytes for the secondary, primary and Gasumo physiognomies at the second phase. Even though, the secondary forest life forms were found to associate to Gasumo, they did show differences at la final phase of the study where they represented 33.69% with a high level Microphanerophytes (41.44%).

The plot of life forms didn't tell how similar are **PF1-GS1**. But, their clustering put them in close proximity due to similarities in life forms composition. The cluster contains approximately the closest proportions in term of canopy architecture of higher canopy trees with 25.78 %; 28. 02 % and 21.64% and 20.01% for Microphanerophytes respectively for the primary and Gasumo forests at the initial phase of research. Moreover, a difference appeared in corresponding Nanophanerophytes with 27.7 % and 18.3% respectively for the primary and Gasumo forests with more epiphytes (38.3 %) than the primary forest.

Figure 103 depicted relationship between life forms in the three phases of vegetation sampling and physiognomic communities under study.



PF1	GS1	SF2	PF2	PF3	GS2	BZ2	BZ 1	BZ3	SF3	GS3	SF1	
742	686	1152	1119	1245	1047	646	786	998	412	349	1215	MPH
167	444	359	231	98	426	101	77	133	398	422	472	E
223	147	397	318	183	395	297	243	356	447	413	430	G
113	120	102	130	41	398	130	228	160	112	186	214	TH
9	110	10	5	13	8	2	52	26	41	10	38	H
2	2	8	8	7	11	37	48	36	9	10	8	CH
748	813	548	714	552	469	184	187	124	629	333	1153	MGPH-MSPH
788	530	502	711	415	293	419	619	389	485	196	953	NPH

Figure 103: Relationship between life forms and clusters of physiognomic communities

4.11.3 Correspondence of life-forms and forest communities' physiognomy

The correspondence between life-forms and forest physiognomy are described at figures 104-105 for the phases of vegetation sampling. With green dots: 1= mega-mesophanerophytes; 2= microphanerophytes; 3=nanophanerophytes; 4= Chamaephytes; 5=Therophytes; 6=Geophytes; 7=Epiphytes; blue dots: 1=buffer zone; 2=secondary forest; 3=primary forest; 4=Gasumo.

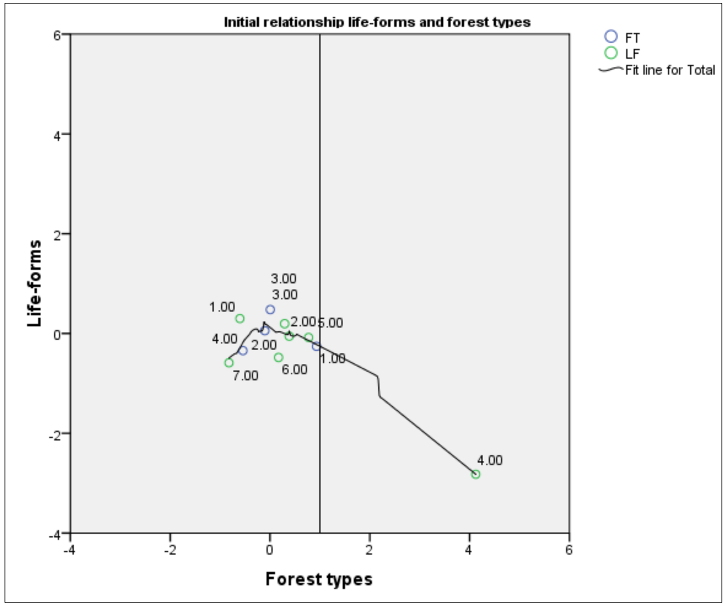


Figure 104: Initial correspondence of LF and FT

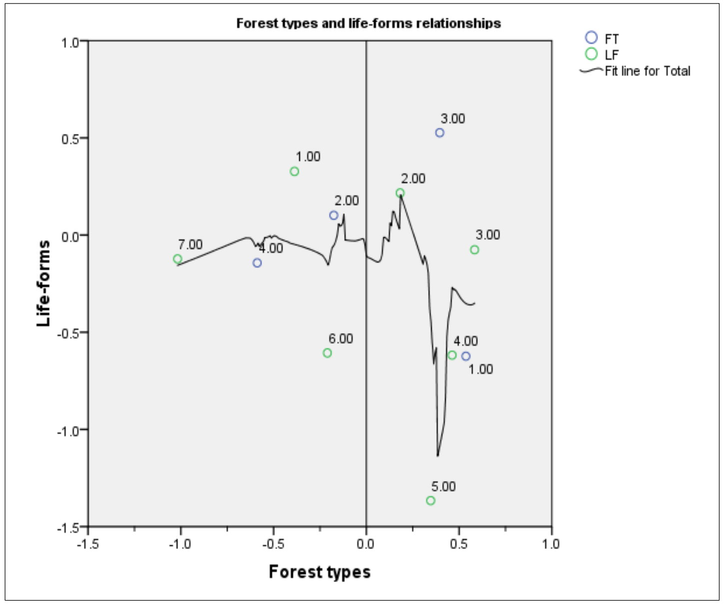


Figure 105: Intermediate correspondence of LF and FT

Figures 104-106 of life-forms showed that higher proportions of Phanerophytes in all physiognomic communities and classes with higher proportions varied differently with the study period. It appeared that the highest proportions of Phanerophytes occurred in the secondary forest for both the initial and the intermediate vegetation survey whereas the subset of microphanerophytes and the nanophanerophytes dominated respectively the initial secondary forest and the intermediate sampleChanges in life-form distribution with increases in proportions where mostly observed for all forms of Phanerophytes whereas the proportion decreased toward the vegetation spectrum in lower life-forms.

Megaphanerophytes and Mesophanerophytes decreased in the general floristic spectrum of the intermediate sampling and increased significantly in secondary forest. In addition, young individuals of Phanerophytes increased for all physiognomic groups and over-expressed in the secondary forest. The figure of correspondence of life forms and forest types at the final vegetation survey is presented at figure 106.

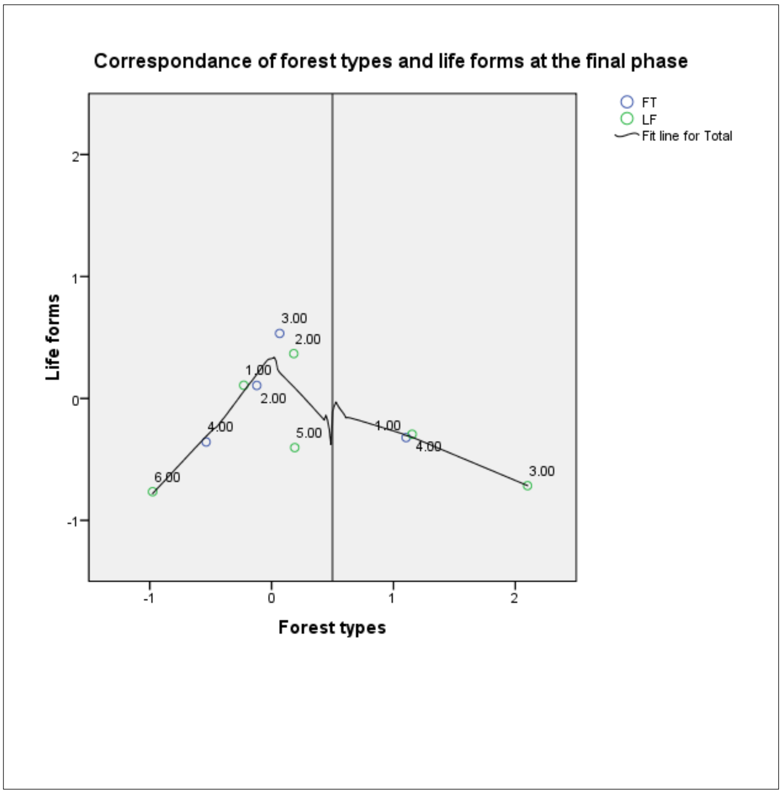


Figure 106: Final correspondence of life forms and forest types

Furthermore, the increase of Phanerophytes frequencies resulted into the absence of Chamaephytes and reduced lower life-forms of Hemicryptophytes, Therophytes and geophytes.

The plotting of life-forms together with physiognomic communities revealed how the disturbance affected life-forms and some life-forms are associated with physiognomic communities Figure 104, 105 and 106 showed that life-forms distribution changed between the sampling periods. At the initial sampling, almost all life-forms and forest types are clustered together except the life-form Hemicryptophytes (4) distanced from the cluster. Phanerophytes (1, 2 and 3) life-forms were significantly associated with the primary and the secondary forests while a strong relationship was detected between geophytes (6) and epiphytes (7) and Nyungwe forest at Gasumo (4) and the secondary forest (2) of Cyamudongo. This may explain the secondary forest nature at Gasumo. The association of Therophytes and geophytes and the buffer zone may be due to the reduced canopy cover which favors the growth of the understorey. The global patterns of the initial life-forms distribution is similar to the correspondence analysis figure obtained using species abundance-dominance and environmental variables. The intermediate life-forms at figure 109 informed about changes that occurred in almost 2 years where life-forms and forest types are scattered in the 2-dimensional spaces with the highest correspondence between Phanerophytes and the primary and secondary forests. Epiphytes are more associated to Gasumo than other forest physiognomy a while a lower level of relationship was found established between Therophytes, geophytes and the buffer zones which were harboring more significantly Hemicryptophytes. The global pattern of life-form spectrum explained better differences among all the components of the data set as observed at figure 107.

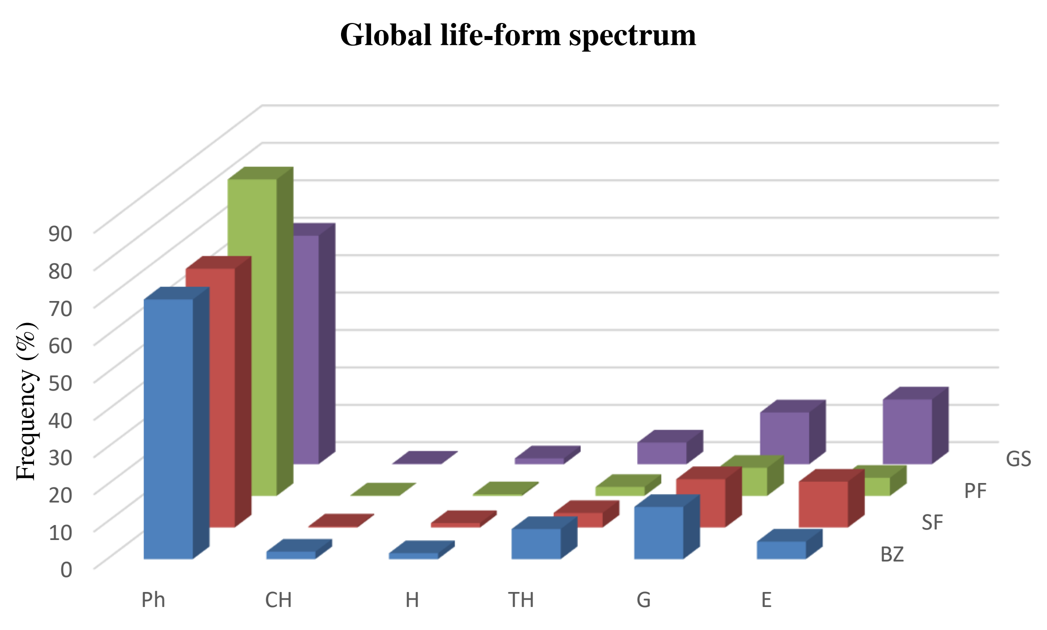


Figure 107: Global life-form spectrum of the three vegetation surveys of the study areas

4.12 Geographical distribution of the flora diversity of the study rea

The recorded flora diversity belonged to different phytogeographical types.

Table 36: Total Phytogeographical types

COS	Species number
A-trp	181
GG	115
A-O-Z	26
A-M	3
COS	11
AM	1
EN (RWA)	13
L-A	1
M	2
Mo(EA)	11
Mo(A-trp)	2
Pal	22
Pan	20
S	49
Z	11
I-Mal	1
Introduced	5
Unlocated	15
Total	**489**

Key: A-trp=Tropical Africa, GC=Guineo-Congolian regional center of endemism; A-O-Z= Afroriental domain/Zambezia regional transition zone; A-M= Africa-Madagascan region; COS=Cosmopolitan; Pal= Paleotropical; Pan=Pantropical; EN (RWA) = Rwandan endemics; L-Am= Latin America; M=Madagascan; Mo (EA) = East Africa Mountains, Mo (A-trp)= Tropical Africa Mountains; S= Sudanian regional center of endemism; Z= Zambesian Center of endemism; I-Mal= Native of India to Malaysia

4.12.1 The chorological spectrum of taxa of the study area

The distribution of taxa in different among phytogeographical regions varied from region to region and the total flora diversity was found to have a large and an Africa multiregional distribution. Most of species belonged to the tropical Africa region, followed by GC=Guineo-Congolian regional center of endemism (table 36 and figure 108).

Some species were restricted to a small geographical area while others had a large distribution.

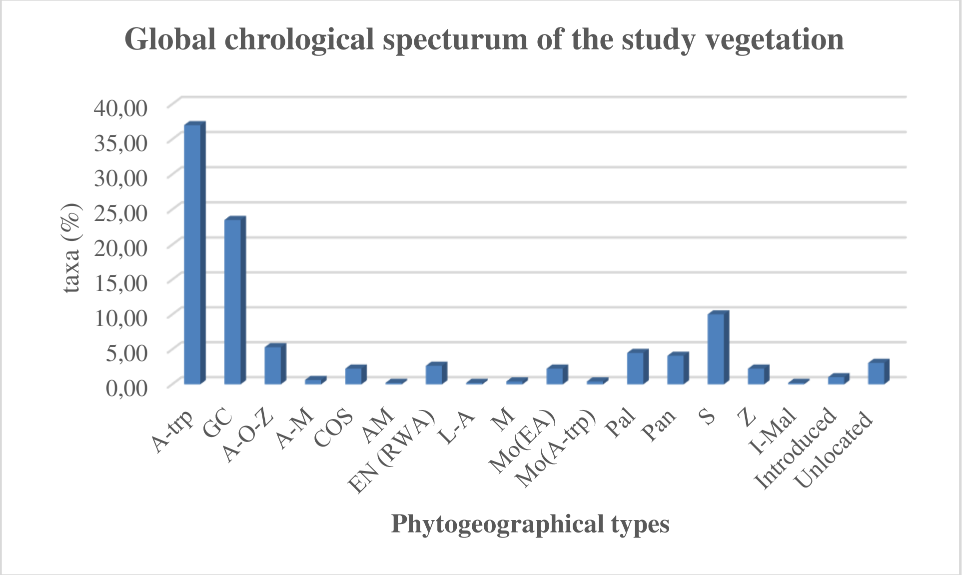


Figure 108: Simplified chorological spectrum of the study vegetation

Table 36 and figure showed that the Tropical Africa, the Guineo-Congolian and the Sudanian regional distribution were the most important distribution domains of the vegetation of Cyamudongo and the study area of Gasumo with respectively 37,01%, 23, 52% and 10,02% of the identified.

4.12.1.1 Species with large distribution

Species recorded in Cyamudongo and the study area of Gasumo respectively included 2.25 %, 4.09 %, 4.50% for the Cosmopolitan, Pantropical and Paleotropical distribution of species.

Cosmopolitan species

Eight taxa were found to have a cosmopolitan distribution: *Christella dentata, Dioscorea sp, Rubus sp Rubia cordifolia, Solanum nigrum, Ageratum conyzoide*s and *Dichrocephala latifolia* as distributed in tropical and temperate zones.

Paleotropical distribution of species

Only 4.5% of the phytocoenose identified and corresponding to 21 taxa were found to have a Paleotropical distribution: *Dicranopteris linearis, Asplenium aethiopicum, Artabotrys sp, Campylospermum sp, Pristimera sp, Zehneria scabra, Desmodium repandum, Dumasia villosa, Vigna luteola, Trema orientalis, Capparis sp., Sida rhomboidea, Triumfetta rhomboidea, Cardiospermum halicacabum, Achyranthes aspera*, *Ceropegia sp., Clerodendrum sp, Viscum sp., Microglossa pyrifolia* and *Vernonia cinerea.*

Pantropical distribution of species

The 4.09% of the total flora diversity recorded which include Tr*ichomanes borbonicum*, *Histiopteris incisa*, *Didymochlaena truncatula*, *Christella dentata, Nephrolepis undulata*, *Piper umbellatum*, *Chlorophytum sp, Commelina benghalensis, Oxalis latifolia, Leea guineensis, Parinari excelsa, Passiflora edulis*, *Phaseolus sp, Paullinia pinnata*, *Rhipsalis baccifera, Drymaria cordata, Conyza sumatrensis*, *Galinsoga ciliata* and *Vernonia auriculifera* had a Pantropical distribution.

4.12.1.2 Africa multiregional distribution of species

The species restricted to a tropical Africa distribution are likely to inhabit tropical forests as they include a diversity of epiphytes such as ferns and orchids such as *Huperzia mildbraedii, Hymenophyllum kuhnii*, *Hymenophyllum dvsp, Trichomanes mannii, Trichomanes dvsp, Antrophyum mannianum, Polystachya dvsp, Begonia sp, Drynaria volkensii and* diverse species of Apleniaceae and Orchidaceae. Epiphytes are favored by of different layers of host canopy trees in the same phytogeographical area such as *Magnistipula butayei, Croton macrostachyus, Rinorea brachypetala, Elaeodendron buchananii, Ficus vallis-choudae, Trilepisium madagascariense, Myrianthus holstii, Bersama abyssinica, Syzygium guineense*, *and Premna angolensis.* The flora composition in this phytogeographical unit include also a diversity of climbers with among them *Cissus petiolata, Rourea sp, Cissus rubiginosa, Flabellaria sp, Momordica cissoides, Leptoderris, Gouania longispicata, Hippocratea parvifolia*, *Dalbergia lactea, Phyllanthus nummulariifoliu*s, *Ficus asperifolia, Ficus natalensis, Salacia erecta, Sericostachys scandens, Landolphia buchananii, Landolphia owariensis, Rauvolfia mannii, etc.*

The phytogeographical pattern of the Tropical Africa unit obtained here did not fix boundaries as some species were distributed on the different phytogeographical unities. In a detailed description of the spectrum, the tropical Africa distribution was concerned with only 59.1% of the species restricted in the phytogeographical unit, species while the distribution of the remaining species is extended to other distribution domains such as in the Afroriental domain, Indian, Pacific and Atlantic islands.

In the Tropical Africa region extended to the Afroriental domain, with this kind of distribution are mostly Pteridophytes like *Asplenium erectum*, *Asplenium friesiorum*, *Asplenium mannii*, *Asplenium megalura, Asplenium sandersonii*, *Dryopteris penther*i, *Polystichum transvaalense, Tectaria gemmifera*, *Arthropteris orientalis*, *Oleandra distenta*, *Pleopeltis excavata*, *Scadoxus multiflorous.* These Pteridophytes extend their distribution to other phytogeographical units in South Africa, Madagascar, and Comoros Island, etc.

At the other hand, species with the tropical Africa distribution were found to extend their area of distribution to South East, in the Usambara-Zululand domain in the scattered relics of rain forest along or near the eastern coast of Africa, extending from southern Kenya southwards into South Africa where *Mariscus longibracteatus*, *Mariscus sumatrensis*, *Cissampelos mucronata*, *Stephania abyssinica*, *Tiliacora funifera*, *Alchornea hirtella*, *Sapium ellipticum*, *Momordica foetida*, *Ficus thonningii*, *Urera trinervis, Ekebergia capensis, Clausena anisata, Blighia unijugata*, *Impatiens hochstetteri*, *Tacazzea apiculat*a, *Oxyanthus speciosus*, *Tarenna pavettoides*, *Kigelia aethiopica* find their habitat. Some species in this geographical area were also found to disperse on islands where they extend to Madagascar, Comoros and India. For instance, *Trichomanes melanotrichum, Blotiella glabra, Asplenium dregeanum, Hymenodictyon sp, Justicia scandens, Thunbergia alata, Ilex mitis* reached the Madagascan domain and *Mikania capensis, Maytenus undata, Celtis gomphophylla* the Comoros islands.

The Guineo-Congolian regional distribution

The second richest phytogeographical unit was found to the Guineo-Congolian regional center of endemism with 23.2% of the total flora diversity identified at Cyamudongo and Nyungwe study area where species are predominantly inhabitants of the rain forest. Under this Phytogeographical unit, some species were restricted to the area while other extended their distribution area to other phytogeographical units thus, defining subcategories in the distribution pattern. Out of 122 species of the Guineo-Congolian phytogeographical unit, most of the species (39.2 %) were confined to the Guineo-Congolian, while 31.5% extended to the

Afroriental domain and 22.13% to the Zambesian. In terms of species composition, different life forms including trees, shrubs, lianas, epiphytes were found restricted to the Guineo-Congolian district with among them *Garcinia volkensii*, *Harungana montana, Carapa spec*, *Musanga leo-errerae*, *Pleiocarpa pycnantha*, *Strophanthus bequaertii*, *Ixora burundiensis*, *Oxyanthus troupinii, Pavetta pierlotii, Pavetta rwandensis, Psychotria avakubiensis, Psychotria ceratoloba*, *Psychotria lebrunii*, *Psychotria parvistipulata*, *Rytigynia ruwenzoriensis*, *Bothriocline nyungwensis*,*Vernonia adolfi-friderici, Adenia sp, Salacia oblongifolia*, *Salacia sp, Begonia ampla* , *Begonia pulcherrima*, etc..

The extension to the Afroriental was characterized by the presence of tree species such as *Lindackeria kivuensis, Symphonia globulifera, Ochna holstii, Ouratea densiflora, and Rinorea gracilipes Entandrophragma excelsum, Dombeya torrida* together with climbers *Uvaria angolensis*, *Tinospora caffra*, *Cyphostemma bambuseti*, *Cyphostemma kilimandscharicum*, *Adenia bequaertii*, *Momordica pterocarpa, Urera hypselodendron, Toddalia asiatica*, *Phytolacca dodecandra, Jasminum abyssinicum*. *Gynura scandens* and a poor diversity of epiphytes and the most species diversity was found the extension on three phytogeographical units with the Guineo-Congolian; Afroriental and the Zambesian with 23% of the overall species diversity of Guineo-Congolian phytogeographical units as described here.

Several others species expended their distribution area in other phytogeographical units for instance in Sudanian, East Africa Mountain, and Zambesian and in Usambara-Zululand. Furthermore, species of trees like *Neoboutonia macrocalyx*, Grewia *mildbraedii*, *Grewia sp, Carapa grandiflora*, *Chrysophyllum gorungosanum*, *Ficalhoa laurifolia, Aidia micrantha*, *Chassalia subochreata*, *Psychotria nigropunctata*, *Rytigynia bugoyensis*, *and Spathodea campanulata* with a lower diversity of climbers such as *Tragia brevipes, Hippocratea apocynoides*, *Coccinia mildbraedii* and a poor richness of epiphytes described the phytogeographical Guineo-Congolian extended to the Zambesian.

Sudanian phytogeographical distribution

The Sudanian district was important after the tropical Africa distribution and the Guineo-Congolian distribution which accounted for 10 % of the total record which include 49 plant species. The diversity under this phytochoria is made of Phanerophytes and Therophytes life forms and epiphytes are rare (Table 36).

Table 37: Sudanian phytogeographical of Species

Species	Life forms	Phyto districts
Culcasia scandens	PH (L)	S
Dracaena laxissima	PH	S-Z
Clematis hirsuta	PH (L)	S-GC-UZ
Hypericum peplidifolium	H	S-Z
Bridelia brideliIfolia	PH	S
Drypetes gerrardii	MGPH	S
Casearia runssorica	MSPH	S-Afro
Dovyalis macrocalyx	MSPH	S
Hippocratea africana	PH (L)	S-Afro-UZ-M
Begonia haullevilleana	E	S
Oreosyce africana	PH (L)	S
Raphidiocystis phyllocalyx	PH (L)	S
Raphidiocystis sp	PH (L)	S
Anthonotha lamprophylla	PH	S-GC
Newtonia buchananii	MGPH	S-Afro
Carpolobia goetzei	PH	S-M
Carpolobia sp	PH	S-M
Dorstenia brownii	TH	S
Dorstenia psilurus	TH	S
Maesopsis eminii	MGPH	S
Alchemilla kiwuensis	TH	S-Afro-UZ-M
Prunus africana	PH	S-Afro-UZ-M
Elatostema monticola	TH	S-Afro
Pilea rivularis	TH	S-Afro-SAR-M
Pilea tetraphylla	TH	S-Afro-SAR-M
Dichaetanthera corymbosa	PH	S
Strombosia scheffleri	PH	S
Harpagocarpus snowdenii	TH	S
Ardisia kivuensis	PH	S
Mimusops bagshawei	PH	S
Ehretia cymosa	PH	S-Afro
Rauvolfia sp	PH (L)	S
Secamone africana	PH (L)	S
Anthocleista grandiflora	PH	S-UZ-Cm
Coffea eugenioides	PH	S
Coffea sp	PH	S
Heinsenia diervilleoides	PH	S
Pauridiantha paucinervis	PH	S-Afro-M
Psychotria mahonii	PH	S
Brillantaisia cicatricosa	TH	S
Thunbergia vogeliana	PH (L)	S
Markhamia lutea	PH	S
Clerodendrum bukobense	PH (L)	S
Chionanthus mildbraedii	PH (L)	S-Afro
Solanum chrysotrichum	PH	S
Solanecio mannii	PH	S-Afro
Vernonia amygdalina	PH	S-Afro

Schefflera abyssinica	PH	S-Afro
Schefflera goetzenii	PH	S

The Sudanian area of distribution for some species extend to the Guineo-Congolian, Afroriental, Zambesian, Usambara Zululand, South of Arabia as well as to Comoros and Madagascan phytogeographical distribution units.

East Africa mountains distribution

The phytogeographical spectrum analysis showed that 2.25% of the record are only distributed in East Africa Mountains. These species include mostly ferns such as *Pteris auquieri, Asplenium bugoiense, Asplenium elliottii, Asplenium linkii* and *Asplenium mildbraedii* with trees like *Beilschmiedia rwandensis, Ocotea usambarensis, Erythrococca fischeri, Annona ferruginea*, Therophytes life form Asparagus *asparagoides and Liparis bowkeri* (Orchidaceae).

4.12.1.3 Exotic species and non-Africa phytogeographical regions

The installation of the buffer zone generated a semi-natural habitat through the regeneration process but also allowed the introduction and naturalization of exotics such *Boehmeria nivea, Boehmeria platyphylla, Eucalyptus sp, Cyphomandra betacea, Cedrela serrata, Grevillea robusta, Pinus patula* and *Persea americana.* The following species were found to belong to non-Africa phytogeographical units: *Sida cordifolia of Latino-America, Kalanchoe integrifolia Rinorea angustifolia with a Madagascan distribution, Psidium guajava* (Tropical America), *Marattia fraxinea* (Brazilian).

4.12.1.4 Endemicity of the study area

Table 38: Endemic species

Species	LF	Phyto districts
Selaginella lewalleana	H	End (RA)
Blotiella bouxiniana	HE	End (RA)
Asplenium rukararense	E, Ge	End (RA)
Beilschmiedia rwandensis	PH	Mo (EA)
Rhipidoglossum delepierreanum	E	END (RwA& BU)
Renealmia orophila	G	End (RA)
Tinospora orophila	PH (L)	END (RwA& BU)
Adenia lewallei	PH (L)	END (RwA& BU)
Begonia pulcherrima	H	END (RwA& BU)
Dorstenia nyungwensis	TH	End (RA)

4.13 Forest community structure in the three phases of vegetation

The tree community structure at Cyamudongo and Gasumo study area was investigated using the measure of dbh and results presented as age classes on the basis of the dbh measure and tree height.

4.13.1 Age class distribution

Figure 109 showed how seedlings, saplings, pole and mature tree species were distributed in different forest landscapes studied.

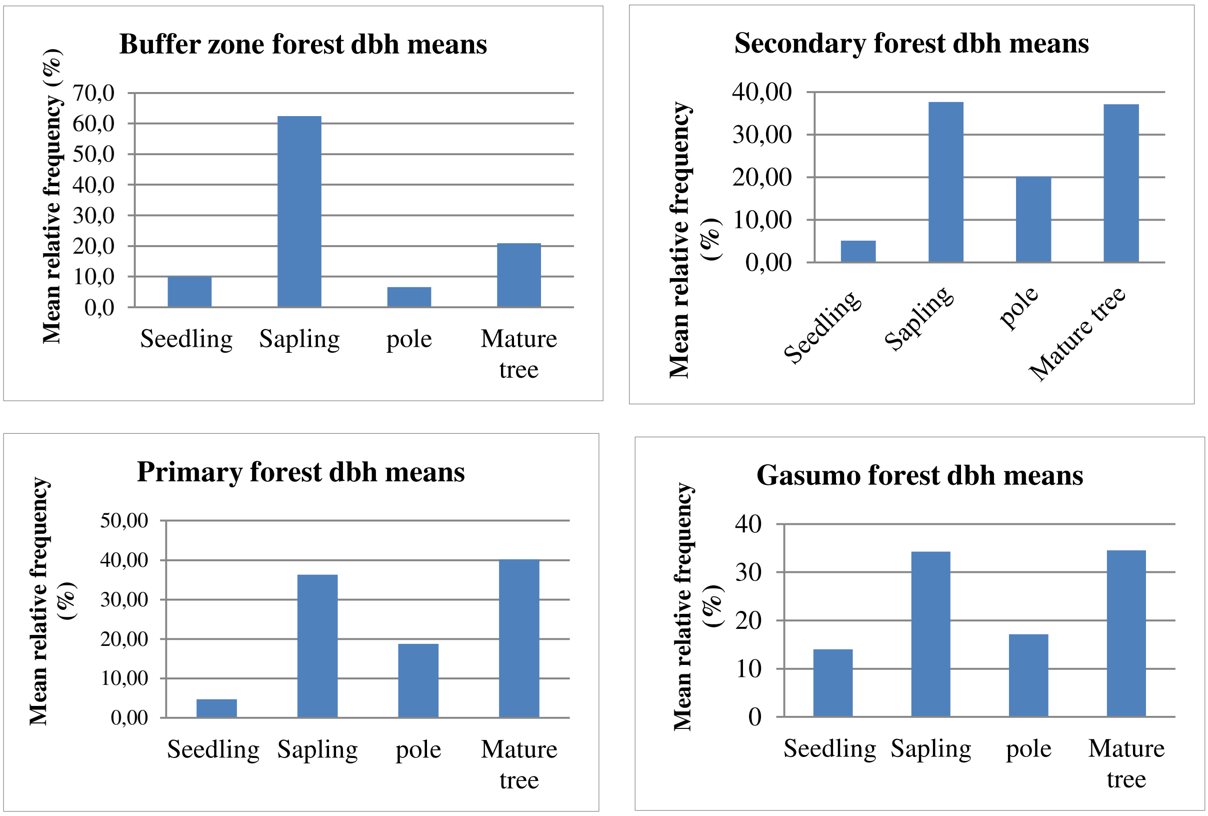


Figure 109: Patterns of age class distribution of woody plants in Cyamudongo and Gasumo forest landscapes

Age class (function of dbh): Seedlings= <2 cm, saplings=2-9.9 cm, poles=10-19.9, mature trees = >19.9 cm.

The results at figure 109 showed that the large proportion of woody plants identified in buffer zone was found in the lower second age class of sapling (2-9.9 cm) with 62% of individual tree found in buffer zone for whole data set. Mature trees (>19.9 cm) accounted for 20.9 %. This resulted in inverted “J” shape distribution pattern for the three phases of the vegetation survey for which means are presented. The proportions of saplings and mature trees were found almost the equal, 37 and 34 % respectively for secondary forest and Gasumo while there has been higher proportions of mature trees (40.2%) in primary forest a bite more that saplings with 36.29% of individuals trees recorded in the three phases of the study. This results gave different pattern where the secondary and Gasumo landscape forests show a pattern with “U’ shape and the primary forest a “J” shape by default with lower proportions of poles. Diameter class distribution as or age class distribution help to understand the general trends in population dynamics and the recruitment process in a given forest stand.

Inverted “J” shape: In this distribution pattern higher proportions are found in lower age class and subsequently so that higher classes are having less proportions in the whole data set. In this study lower age class in the buffer (sapling) has a higher proportion while mature trees owned less proportions which increased up to the higher age class.

‘U’ shape: The pattern shows higher proportions of individuals in the lower and the highest age classes while the intermediate class contains les proportions. In the secondary and Gasumo forests saplings and mature trees held equal proportions of individuals while the intermediate class of poles declined deeper.

“J” shape: The ‘J’ shape pattern shows that there is less proportions in the lower age classes increasing up the highest age class. This is the case in the primary forest where proportions increased up the mature trees. In terms of species, the records showed that mature trees with largest dbh were predominantly found in primary forest of Cyamudongo, followed by the secondary forest and Gasumo at a same level. For instance, the 13 largest mature trees in primary forest were found to be *Celtis gomphophylla, Chrysophyllum gorungosanum, Ekebergia capensis, Elaeodendron buchananii, Entandrophragma excelsum, Ficus thonningii, Ficus vallis-choudae, Manilkara obovata, Newtonia buchananii, Parinari excelsa, Premna angolensis, Prunus africana, Trilepisium madagascariense* with a diameter at breast height (dbh) ≥100 cm. Moreover, the diversity of largest mature trees changed in species composition with a decline in number in the secondary forest. *Carapa grandiflora, Drypetes gerardii, Myrianthus holstii, Polyscias fulva and Strombosia scheffleri* were found present and absent largest mature trees found in the primary forest *like Celtis gomphophylla, Ekebergia capensis, Entandrophragma excelsum, Ficus vallis-choudae, Manilkara obovata, Premna angolensis*, and *Prunus africana* was observed. Chrysophyllum gorungosanum**,** *Elaeodendron buchananii*, *Ficus thonningii*, *Newtonia buchananii* and *Trilepisium madagascariense* were common to the Primary and secondary forests.

Gasumo was found to have only three tree species in the largest mature trees such as *Newtonia buchananii*, *Parinari excelsa*, *and Strombosia scheffleri* while the observed tree range was totally absent in the buffer zone areas. These higher biological forms distribution affected subsequent forms with a significant decrease of poles that favors more the secondary forest, Gasumo and the primary forest than the buffer zone. The buffer zone was found younger than other forest communities with high frequency of saplings in species composition followed by Gasumo may be due to past disturbance but with good signs of forest recovery following human disturbances. This reflected again the secondary nature of the studied of Gasumo communities which were likely to cluster under secondary forests equalizing sapling and mature trees frequencies. Furthermore, seedlings were found more frequently in than buffer zones and Gasumo that in primary and secondary forests. Tree distributions per diameter (dbh) classes did not change markedly between the two surveys in the four types of forest except for the declining of frequencies of tree seedlings of the dbh < 2cm class in all habitats but with a slight increase of saplings, pole and mature trees and highest frequencies of saplings and mature trees. The highest frequencies of seedlings and saplings at Gasumo and in the buffer zone and secondary forest of Cyamudongo with a decrease of seedlings at the second survey suggest an overlap of forest disturbances and recovery. The final vegetation survey showed a little difference with the intermediate. The patterns observed in all landscapes are almost the same. From the initial survey seedlings in all physionomic communities have decreased while a high frequency of saplings was observed at all phases of the study in all forest types but with dominance in the buffer zone.

Table 39: Largest tree dbh per forest type

Tree species	BZ	SF	PF	GS
Alangium chinense		x	x	
Carapa grandiflora				x
Carapa spec		x		x
Celtis gomphophylla		x	x	
Chrysophyllum gorungosanum		x	x	x
Croton macrostachyus			x	
Croton megalocarpus		x	x	
Drypetes gerrardii			x	x
Ekebergia capensis			x	
Elaeodendron buchananii	*x*	x	x	x
Entandrophragma excelsum	*x*	x		
Ficus sur			x	
Ficus thonningii	*x*	x	x	
Ficus vallis-choudae			x	
Grewia sp.			x	x
Harungana montana				x
Macaranga kilimandscharica		x		
Magnistipula butayei			x	
Musanga leo-errerae			x	x
Myrianthus holstii			x	x
Newtonia buchananii	*x*	x	x	x
Pancovia golungensis			x	
Parinari excelsa			x	x
Pinus patula	x			
Polyscias fulva		x	x	
Premna angolensis			x	
Prunus africana				x
Sapium ellipticum		x	x	x
Strombosia scheffleri		x		x
Symphonia globulifera			x	x
Syzygium guineense		x		x
Tabernaemontana stapfiana		x		
Trema orientalis				x
Trilepisium madagascariense			x	
Xymalos monospora			x	
Zanthoxylum gilletii				x
Total	**5**	**15**	**24**	**18**

In dbh of mature tree species ranging between 51 and 275 cm, primary forests are more diverse than the Gasumo and the secondary forests with 38,71%, 29,03%; 24,19% of taxa. The buffer was found poor (8.06%) and dominated by exotic trees mostly Pinus patula used forest afforestation and dbh ranging between 51 and 75cm. Canopy cover and disturbance level are in relationship with the range of dbh where the increased canopy cover and reduction of the level of disturbance favor tree growth with good features in terms of dbh and height. According to the table 16, some tree species are confined to one or another type of forest indicating the extent of human activities on the physiognomic groups. Primary forests harbor the highest number of large dbh tree species. The list includes *Ekebergia capensis, Ficus sur, Ficus vallis-choudae, Magnistipula butayei, Pancovia golungensis, Premna angolensis, Trilepisium madagascariense, Xymalos monospora.* The lowest level of disturbance, species habitat restriction and specialization, species geographical territory should be responsible for this larger dbh tree species presence. However, *Tabernaemontana stapfiana, Macaranga kilimandscharica* are found restricted in the secondary forest physiognomy while *Macaranga kilimandscharica, Harungana montana, Prunus africana, Trema orientalis, Zanthoxylum gilletii* characterize communities of Gasumo studied area. These differences in megaphanerophytes species composition confirm differences in species distribution in Cyamudongo fragment and Nyungwe and their role in shaping the species diversity of the understorey flora.

4.13.2 Height class distribution

In the three study periods, the large proportions of tree species were generally found in the lower height classes mainly in the first three classes [(< 5m), (5-10 m), (10-15m)].

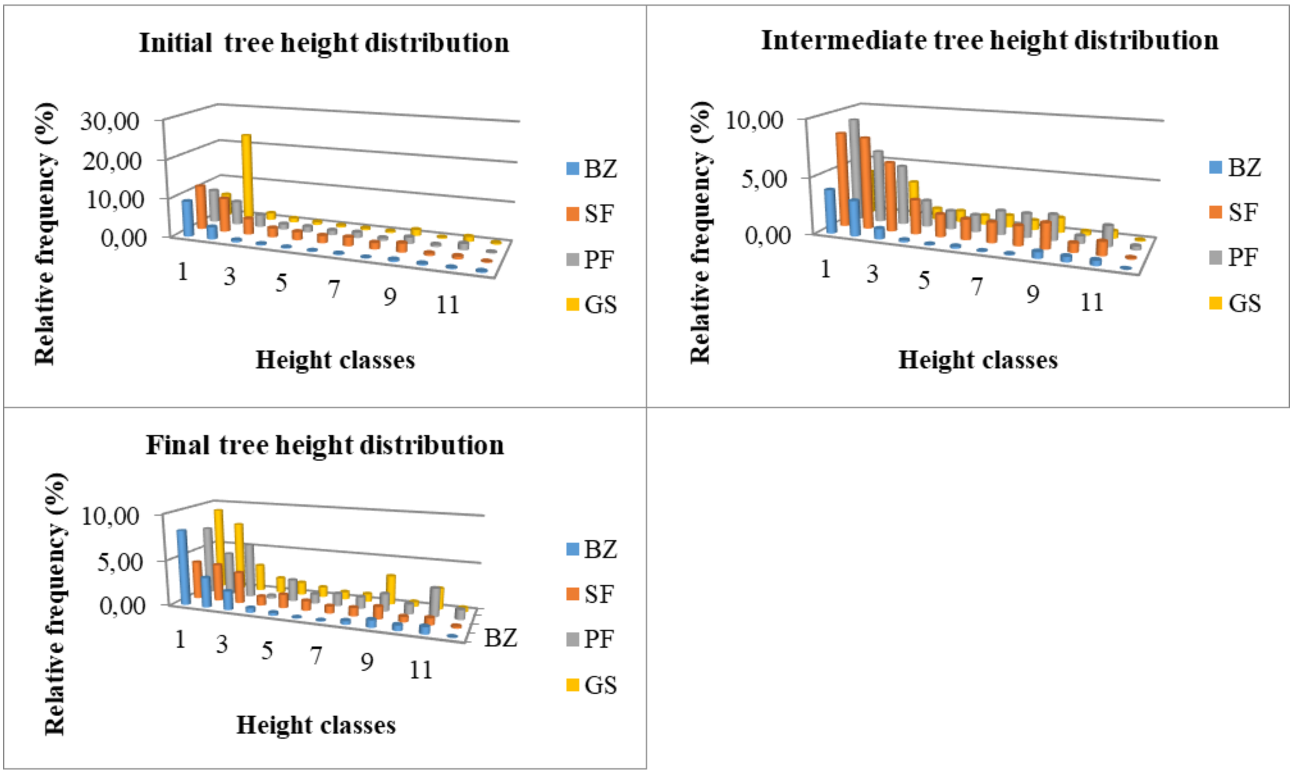


Figure 110: Height class distribution in Cyamudongo landscapes and Gasumo forest

Height class: 1= 1- 5m, 2= 5-10 m, 3= 10-15m, 4= 15-20m, 5= 20-25m, 6=25-30m, 7=30-35m, 8=35-40m, 9=40-45m, 10=45-50m, 11=50-55m, 12>60m.

The patterns of height class distribution at all the vegetation surveys showed a general height class distribution in the buffer zone, secondary, primary and Gasumo forest landscapes. The patterns showed a J-shape height class distribution where in both considerable proportions of tree frequencies (figure 110). As indicated in figure 109, the first class (1-5m) consisted of 7.06%, 7.9%, 8.4% and 6.3% respectively out of 12 classes for the buffer zone, secondary forest, and primary forest and Gasumo landscapes, in the mean of proportional frequencies in the three phases of the study. Although, all Individuals from upper height class (taller than 30 m) contributed with less that 2.5% in average. The buffer zone owned the lowest relative frequency in all research period Gasumo dominated on the last study phase and the second class (5-10 m) of the initial vegetation survey. Similar trends are observed between the primary and the secondary forest for the initial and intermediate phase and differentiated at the final survey.

Table 40: Statistics of height class

Stat	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12
N	12	12	12	12	12	12	12	12	12	12	12	12
Min	3.86	3.12	0.52	0.18	0.08	0.08	0.05	0.08	0.44	0.27	0.22	0
Max	11.4	22.8	6.09	3.02	2.37	1.9	2.22	2.11	3.15	1.06	3.03	1.06
Sum	88.9	81.8	39.3	15.1	14.7	11.3	12.4	10.97	19.4	6.73	14.6	3.27
Mean	7.4	6.8	3.3	1.26	1.23	0.94	1.03	0.9	1.61	0.6	1.3	0.2725
Std. error	0.7	1.6	0.5	0.3	0.22	0.18	0.22	0.19	0.23	0.06	0.23	0.08
Variance	6	29.5	3.3	0.8	0.5	0.38	0.57	0.43	0.64	0.045	0.7	0.079
Stand. Dev	2.4	5.44	1.8	0.92	0.77	0.62	0.75	0.65	0.793	0.212	0.83	0.28
Median	8.25	5.4	3.205	1.025	1.425	1.04	0.93	0.85	1.605	0.555	0.965	0.2

4.13.3 Similarity of forest landscapes based on height class distribution

The hierarchical clustering using Word's Methods discarded the data set of the Gasumo intermediate survey as a separate cluster. The main cluster split in two sub-clusters containing subsidiaries (Fig. 111).

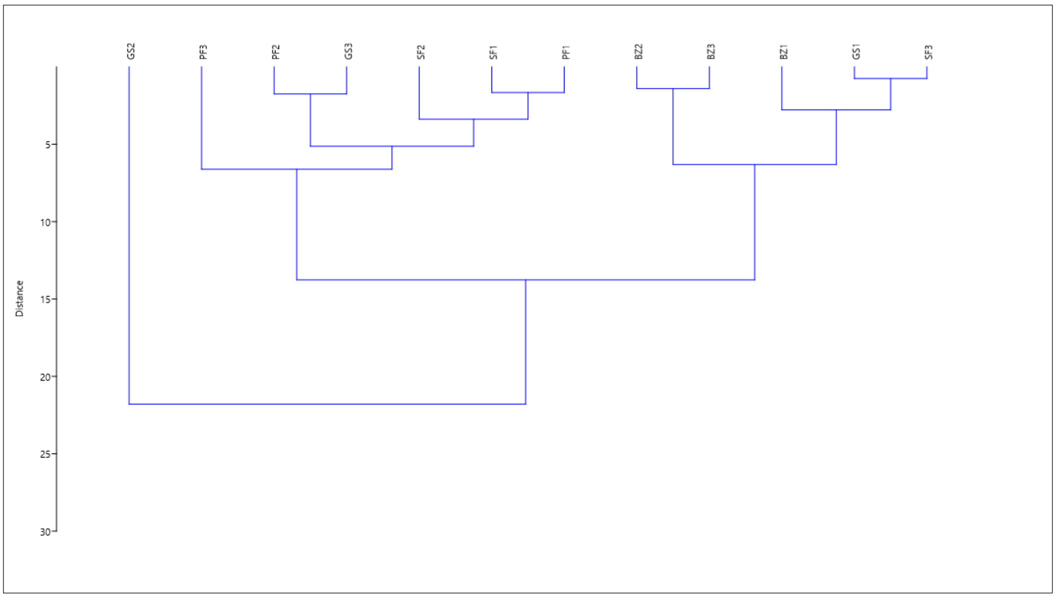


Figure 111: Group cluster base on similarity in height class distribution

The main cluster groups are cluster group I which include GS2 only and the cluster group II splitting into two sub-clusters (Sub-cluster I and sub- cluster 2).

The sub-cluster I contains cluster subsidiaries of the buffer zone (BZ2&BZ3) stands and the Buffer (BZ1) and GS1-SF3) which both may due to the lower height classes with less frequencies in individuals and upper height classes with lowest frequencies in high canopy trees. At the other hand, the sub-cluster II splits to put together the primary forest (PF1) and the secondary forest (SF1 & SF2) sharing apparently more similarities of tree relative frequencies in corresponding height class (Fig. 111) while the closest similar PF2 and GS3 discarded from PF3.

4.13.4 Tree height in community structure

The relationship between tree height and types of forest displayed a positive correlation (Fig. 112).

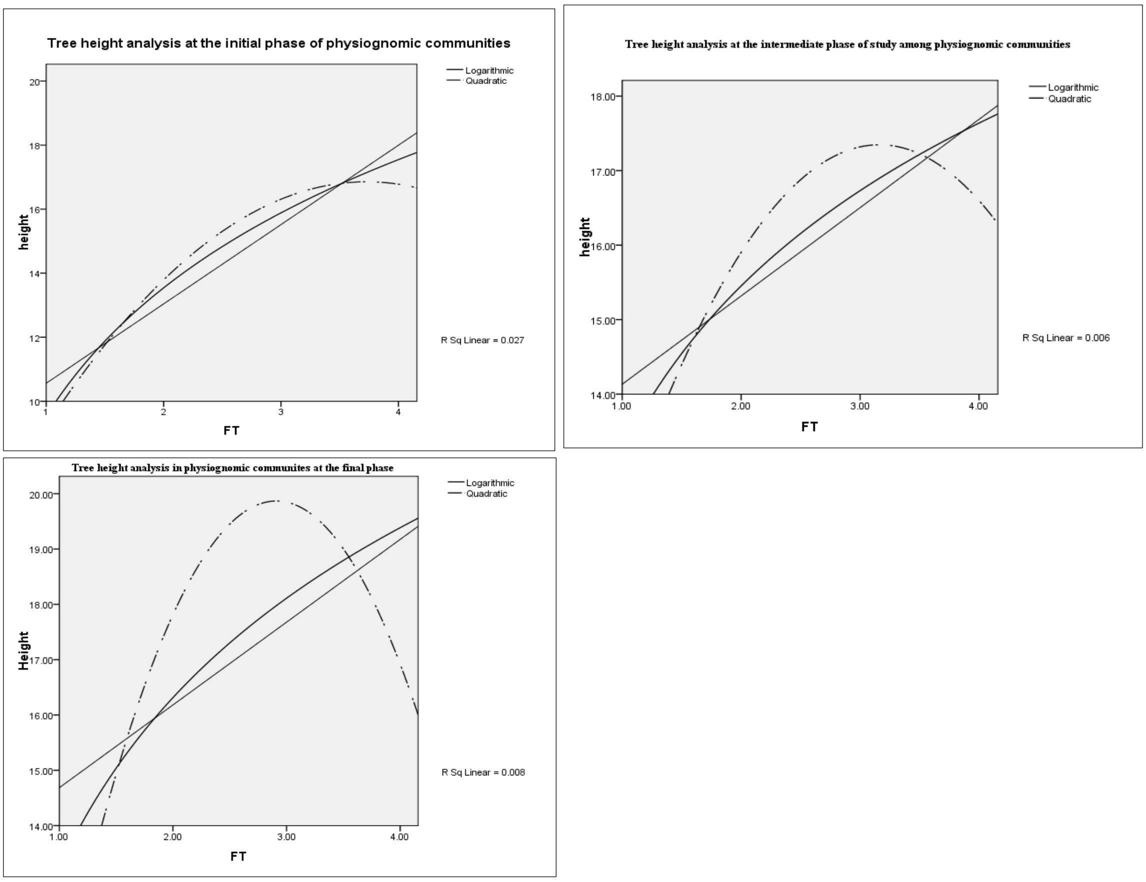


Figure 112: Regression analysis of tree height among forest landscapes

The figure 112 present results of regression analysis of the data set of the vegetation surveys on recorded height in landscapes forest studied.

It appeared that R squared for the linear regression was 0.027, 0.006 and 0.008 respectively for the initial, intermediate and the final vegetation of the forest landscapes under study. These R^2 are very low, close to 0 and indicate a weak positive relationship between the studied forest landscapes and height of trees recorded in corresponding sites. Moreover, the trend lines in respective study periods show that lowest height classes were found in the buffer zones while the primary forest held the highest tree height following. The trends lines showed also that the height decline in Gasumo landscape forest. The low R^2 obtained in regression analysis of height and forest types in the three phases of the study, indicates that forest types are not explaining much in the variation of the height and the canopy height may have been affected by the level of disturbance as the forest physiognomy were identified by the disturbance level. For instance, the primary forest showed a high canopy height compared to others.

CHAPTER 5. DISCUSSION

5.1 Changes in Vegetation cover

The growing population is always impaired with a growing need of food and land for settlement. The rate of forest destruction and land conversion to farming, pasture expansion, and population shelters have increased during the recent years (Zaitunah *et al*., 2018) mostly the tropical rainforests have been more threatened by human lead activities as detailed by Corlett & Primack (2006). The lasting effects of forest destruction has been the direct threats to humid tropical forest biodiversity which included extraction of plants and animal, introduction of invasive species, forest fragmentation, change in environment and the local and global climate.

Since its designation as a forest reserve and later as a National Park, Nyungwe suffered from gaps linked to the management until donors agreed to a management plan and to funding initiatives which stopped during the 1994 genocide. The government agency (Office Rwandais du Tourisme et des Parcs Nationaux-ORTPN) maintained a symbolic protection with 20 staffs not enough to cover the large forest. The partnership with WCS allowed to recruit and train more staff and consequently improved the management and the protection of NNP (Rutagarama & Martin, 2006).

In the effort to preserve the functional diversity of Nyungwe, the University of Koblenz-Landau under Cyamudongo project implemented a five years' project around Cyamudongo where the general tangible output has been the land cover change detected and revealed by the trends of NDVI obtained from the satellite and corresponding maps. The NDVI intervene in this study as an indicator of ecosystem health as the degradation or the decrease in greenness of the vegetation is thought to be reflected in decrease of NDVI values (Tovar, 2011). This method is a satellite based tool proven useful to study the forest cover change due to their capacity to cover a large area (Kayiranga *et al*., 2016). NDVI trends showed that there have been fluctuations in vegetation classifications of the studied area. It appeared that the vegetation cover changed from 2016-2018 with increase of NDVI values and decrease of surface area in lower levels and increase in high levels classifications but with a general increase of higher dense vegetation. Although, the year 2019 behaved differently with a decreasing trend in NDVI and the corresponding surface area while a positive trend of the 2020, remained inferior to the trend of 2018. It is assumed that the changes in NDVI values and their corresponding surface areas depend heavily on changes occurring at the level of the ecosystem causing fluctuations on vegetation types, quantity and quality (Huang *et al.*, 2019). One of causes of changes may be the positive impact of Cyamudongo project involved in tree planting in surroundings of Cyamudongo among others which may have increased the NDVI values as reported by Li *et al.* (2011). Detailed analysis of weather conditions would have helped to understand the decreasing trend in 2019 NDVI as proposed by Huang *et al.* (2019) that the hydrothermal combination reduces the precipitation and the relative humidity with a significant increase of sunshine duration resulting in drought and a decrease in NDVI values. At the other hand, the statement of Tovar (2011) disagreed and added that the a forest can experience a change in vegetation cover without losing its original condition.

The fact that the lowest density of vegetation was found in surroundings of the park, in buffer zones, mostly at Mataba (South-West) and the center directed to the north of Cyamudongo as well as the patches at the north east of the studied area of Gasumo corroborated with the argument that there is more aerial biomass in the primary ecosystems than those affected by a high level of disturbance (Tovar, 2011).

Although, Nyungwe and Cyamudongo fragment are protected areas, the results of this showed there has been significant trends of forest cover decrease since 2016, this scenario has been described on the entire NNP and Kibira in Burundi where others have identified forest losses that attributed to anthropogenic activities and forest losses despite protocol governing National Parks (Kayiranga *et al.*, 2016). At the end of the study, the results showed that a higher dense vegetation dominated other vegetation classifications than it has been the period before where the land cover tend to increase and stabilize due to low deforestation rate and increase in conservation and efforts of reforestation in the region as supported by Basnet &Vodacek (2015). A postulate on a dense forest corresponding to the dominant class in the current classification qualified it as having more than 70% of tree canopy cover with 40 to 70% cover of moderate forests and sparse forest as 10-40% cover (Barthlott *et al.*, 2005).

5.2 Floristic composition

Cyamudongo and Nyungwe like other rain forest exhibit a high diversity in terms of community structure and composition which are characterized by broad-leaved trees with large buttress supporting climbers, epiphytes and hemi-epiphytes and a multi-layered canopy as argued Zakaria *et al.*(2016). From the results of this study, 494 vascular plant species that included the Spermatophyta and Pteridophyta were present in 315 plots. 153 species were common to primary, secondary and buffer zone of Cyamudongo and 115 common to Cyamudongo and Gasumo studied landscapes. 27 species were restricted to Gasumo and 62 present exclusively in Cyamudongo.

With reference to Nyungwe National Park, the total phytocoenose obtained was almost 46,25% of `the total number of plant species estimated for Nyungwe National Park as suggested by Musabwamana (2019), who estimated the total number of species of the whole massive at 1068 plant species. In addition, results findings showed a huge difference between Cyamudongo and Nyungwe, with 48.54% of vascular plant species found to be confined to Cyamudongo while very few (7.92%) were restricted to Gasumo.

Differences observed between the diversity of species occuring in Cyamodongo and the closest area of Nyungwe main block allowed to support the argument of the existence of refugial area in mountain ridges around Lake Kivu and of unicity of the flora and vegetation of Cyamudongo (Fischer & Killmann, 2008). The genetic drift and isolation may help to inderstand these differences as interpreted as widespread of self-pollination and population in-breeding which benefit scattered distributions of highly specialized species (Hill & Hill, 2001) since Cyamudongo was isolated since a 100 years (Fischer & Killmann, 2008).

Furhermore, at 0.30% surface area, occurred 41.39% of the total florule of Nyungwe National Park therefore supported by Musabwamana (2019), Kanyamibwa (2001) and Fischer & Killmann (2008) where the surface rea of Cyamadongo forest is 300 ha compared to the surface area of Nyungwe and the whole massif of Nyungwe accounting for 101,508 ha (Arakwiye *et al.*, 2021).

Results proven that among the Spermatophyta, Angiosperms were highly dominant with 84.9 % of the total species number against 13.2% of Pteridophytes. The occurrence of Pteridophytes a side to angiosperms has been portrayed by Branch (2014) who asserted that ferns have passively benefited from the increased precipitation that accompanied the angiosperm diversification in tropical rain forests which favored the climate regime due to their evapotranspiration. The disturbance was found to affect species diversity in the studied areas where the diversity varied between in the landscapes with less diversity in buffer zone compared to others. This agreed with the statement of Gogoi & Sahoo (2018) that higher degree of disturbance was furtherly found not only to affect species diversity but also promoting the growth of invasive weed species like mostly *Solanum chrysotrichum* observed occurred mostly in the buffer zone and the secondary forest. The primary forest was found to have less species occurrence when compared with the secondary forest physiognomy but the occurrence of dominant species in the largely undisturbed site and common species in the least and mildly disturbed site also strongly indicated the effect of forest disturbances in the studied three communities at Gasumo as asserted by Gogoi & Sahoo (2018).

5.3. Richness

The flora diversity in the study area was found to belong to 106 families where the top 12 vascular plant families were dominated respectively by families of Rubiaceae, Aspleniaceae, Asteraceae, Orchidaceae, Apocynaceae, Fabaceae, Urticaceae, Moraceae, Acanthaceae, Euphorbiaceae, Sapindaceae, Meliaceae and 75 % of them are reported to be the richest in Africa tropical forests (Sosef *et al.*, 2017) represented respectively by Rubiaceae, Fabaceae, Orchidaceae, Asteraceae, Poaceae, Acanthaceae, Cyperaceae, Apocynaceae, Malvaceae, Euphorbiaceae, Lamiaceae, Annonaceae, Melastomataceae, Phyllanthaceae, Sapindaceae, Celastraceae, Sapotaceae, Asparagaceae, Convolvulaceae, Polypodiaceae. Furthermore, the richness in families were found almost similar to the finding in in the Kahuzi-Biega National Park, within the Albertine Rift with the dominance over different life forms by the Families of Rubiaceae and Fabaceae (Cirimwami *et a*l., 2019). Moreover, the diversity of the studied areas was found relatively very low compared to the Amazonian lowland rain forest with 14,003 species, 1,788 genera and 188 families of seed plants, but with almost the same dominating families with Leguminosae (Fabaceae), the most species-rich family, followed by Rubiaceae (Cardoso *et al.*, 2017) as observed in the study done in North West region of Cameroon (Amos *et al.*, 2019).

The distribution of families and species varied among Cyamudongo landscapes and Gasumo and depended on the disturbance level. Diversities varied across and within vegetation types as argued by Carvalho *et al.*(2020) with some families absent of light demanding species in understorey such as Asteraceae and families of pioneers species in primary forest and the species richness of the families with more shade-tolerant species such as Piperaceae, Urticaceae or dominant ranks of some families have changed with the types of landscape as stated by Zhu *et al*. (2004).

5.4 New records for Rwanda

Based on the existing flora of Rwanda, some of them were known by the species names and others only by genus names and arranged in order of their families according to APG III as follow:

1. *Illigera pentaphylla* Welw.- Hernandiaceae

Figure 113: Young *Illigera pentaphylla* taken in Cyamudongo

Botanical description: Liana 3-15 m long with woody stem tendrils and digitate leaves with 3-4 thick leaflets and 5 at maturity and greenish flower buds.

http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:430854-1 accessed on 15th March 2021.

Ecology*:* Evergreen forest edges, road-sides; 1140-1650 m alt but the plant has been discovered in Cyamudongo between 1775 and 2020 m of altitude in different physiognomic communities under the shade of canopy trees.

Illigera pentaphylla distribution

The species occupy mostly the Guineo-Congolian territory of the Tropical Africa in the sub-saharian region with a wide distribution in Central Africa (Guinea, Ivory Coast, Nigeria, Cameroon, DRC, and Angola) and in East Africa (South Sudan, Uganda, Kenya, and Tanzania).

The map below shows that *Illigera pentaphylla* Welw had a large distribution in Central and West Africa.

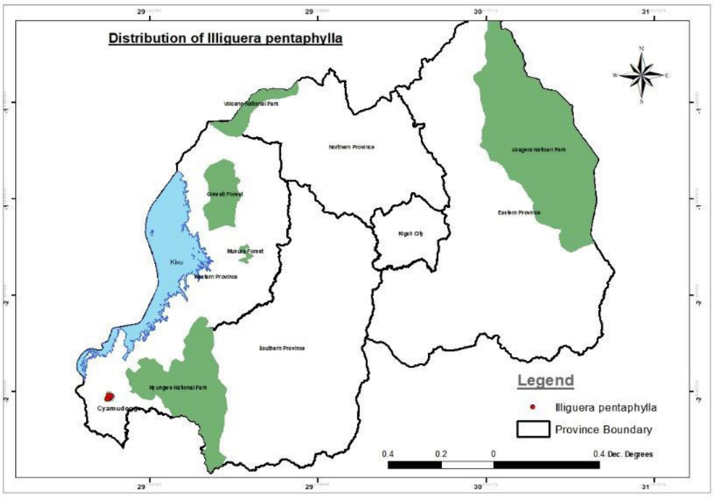


Figure 114: Distribution map of Illigera pentaphylla Welw

2. Hetaeria heterosepala (Rchb. f.) Summerh -Orchidaceae

Synonyms: *Cheirostylis heterosepala* Rchb. f.; *Zeuxine heterosepala* (Rchb. f.) Geerinck.

The photo below this species describes the species habitat.

Figure 115*: Hetaeria heterosepala* (Rchb. f.) Summerh taken at Kabingo

Botanical description: ***Hetaeria heterosepala*** **(Rchb. f.) is a** Perennial herb; rhizome fleshy, 3-4 mm Ø; upright part of stem 12-20 cm long, glandular above; leaves 3-7, spirally arranged, in middle of stem, petiole and sheath 0,7-1,2 cm long, blade ovate, acute, 1,5-5x0,6-1,8 cm; raceme 2-6 cm long, densely 3-20-flowered; bracts lanceolate, 5-8 mm long, margins fimbriate; flowers small, usually non-resupinate, green and white; tepals thin, delicate; dorsal sepal elliptic, 4-5x1,7-2,5 mm, adnate to petals to form a hood over column; laterals similar, saccate at base; petals falcate, c. 4x1,5 mm; lip c. 5 mm long, constricted above middle, basal part saccate, with 2 recurved hooked calli at base, apical part deflexed, 2-lobed, lobes large, divergent; ovary 6-8 mm long, glandular (Gamarra *et al*., 2019).

Distribution of *Hetaeria heterosepala* (Rchb. f.)

The map at figure describes the distribution of *Hetaeria heterosepala* (Rchb. f.) Summerh in West and Central Africa (Ivory Coast, Cameroon, DRC) in Tanzania in East Africa and Madagascar.

Source: http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:638716-1 5

In Rwanda, the species was found to occur in Nyungwe at Kabingo.

Ecology: Humid forests: in grassfield near river, mountain slopes; 425-1000 m alt and between 1693-1763 m alt in Rwanda at Kabingo (Nyungwe).

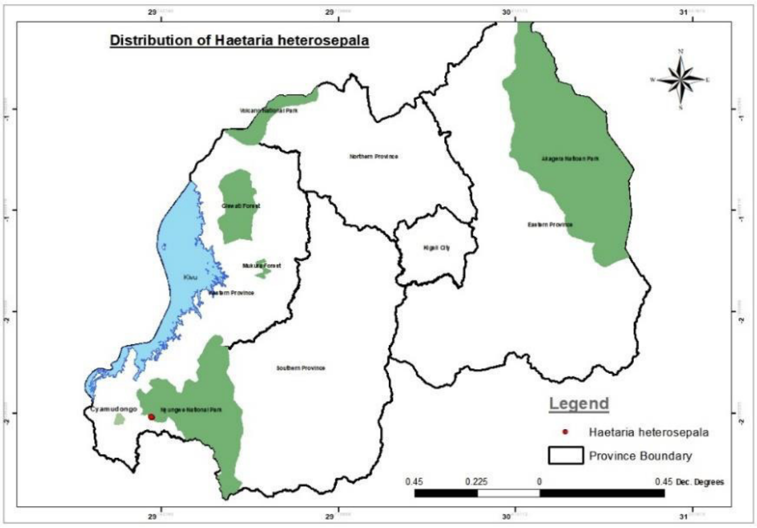


Figure 116: Distribution map of *Hetaeria heterosepala* (Rchb. f.)

3. *Begonia ampla* Hook. F. - Begoniaceae

Synonym: ***Begonia duruensis*** De Wild.

Botanical description: ***Begonia ampla*** **Hook** is Perennial stout epiphyte, not or scarcely branched, to 2 m tall and stem 1,8 cm ; older parts of stem woody, with hooflike scars of fallen leaves and with adventitious roots at nodes; fruit a berry. Monœcious. Stem very stout, woody, together with the petioles and nerves beneath sparsely furfuraceous, young leaves densely clothed with rusty stellate down. Leaves long-petioled, 8–10 in. diameter, obliquely suborbicular or very broadly obliquely ovate, deeply cordate, abruptly contracted into a slender point, obscurely toothed at the tip of the once or twice forked nerves, palmately 6-nerved, upper surface with a few scattered minute stellate membranous scales that are more numerous below; petiole stout, 5–8 in.; stipules large, green, convolute, 1 1/2 in. deciduous. Peduncle stout, 1–2 in., terminated by 2 large convolute orbicular bracts together forming a subcampanulate cup 3/4 in. long and broad, enclosing numerous shortly pedicelled flowers. Male fl.: Sepals 2, rose-coloured, orbicular-obovate, 1 in. long. Anthers small, subsessile, linear, obtuse. Female fl.: Sepals of the male. Styles 3–4, short, free; stigmas forked, branches rather long, papillose band broad, continuous, twisted. Ovary 3–4-angled. Berry enclosed in the bracts, subglobose, 1/2 in diameter; placentas much branched.

(https://plants.jstor.org/stable/10.5555/al.ap.flora.flota003266?searchUri=qtype%3Dall%26query%3DBegonia%2Bampla accessed on 6th March 6, 2021).[5]

http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:104165-1on accessed on 6th March 6, 2021[6].

Figure 117: ***Begonia ampla*** **Hook. F. taken at Gasumo**

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[5] https://plants.jstor.org/stable/10.5555/al.ap.flora.flota003266?searchUri=qtype%3Dall%26query%3DBegonia%2Bampla accessed on 6th March 6, 2021).[5]

[6] http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:104165-1on accessed

Distribution of *Begonia ampla* Hook. F.

Rain-forest; at edges of watercourses or in swamps; 1-1400 m alt. – Also cultivated locally.obon, S. Tomé and found in Nyungwe at Gasumo, 1685-1841 m alt.

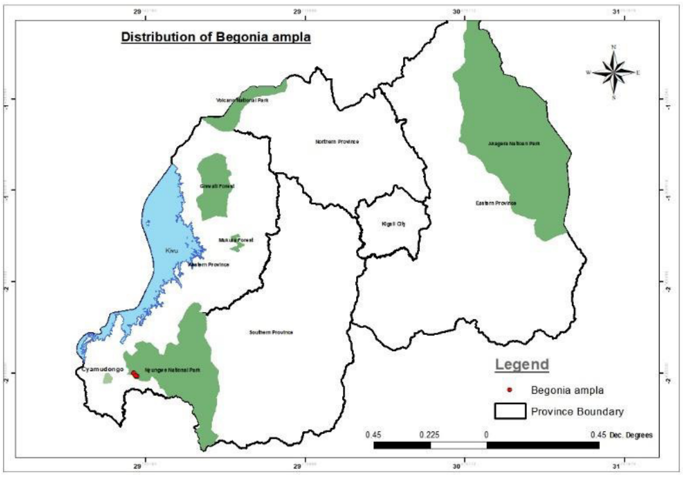

Figure 118: Distribution map of *Begonia ampla* Hook. F.

4. *Dorstenia psilurus* Welw.

Synonym(s) Homotypic: *Dorstenia psilurus* Welw. *var. psilurus*

Synonym(s) Heterotypic: *Dorstenia bicornis* Schweinf. *Dorstenia lukafuensis* De Wild., *Dorstenia psiluroides* f. *subintegra* Engl.; *Dorstenia psiluroides* Engl..; *Dorstenia psilurus var. brevicaudata* Rendle; *Dorstenia psilurus var. compacta* De Wild.; *Dorstenia stolzii* Engl.[7]

Botanical description of *Dorstenia psilurus* Welw.[8]

Herb up to 60 cm. tall in Flora area but to 2(–3) m. in var. scabra, rhizomatous; rhizome often ± tuberous; stems erect or ascending, often branched, ± 3(–5) mm. thick, puberulous. \Leaves in spirals, ± crowded at the apex of the stem; lamina papyraceous when dry, elliptic to obovate, (2–)5–19 × (1–)2–8 cm., apex acute to acuminate, base cuneate, margin denticulate to coarsely dentate or sometimes repand; both surfaces puberulous; lateral veins 5–8(–10) pairs; petiole 0.5–3.5 cm. long, 1–2 mm. thick; stipules narrowly triangular, 0.5–2(–4) mm. long, subpersistent. Inflorescences solitary or in pairs; peduncle 0.6–5 cm. long, ± 0.5 mm. thick. Receptacle vertical, naviculate; flowering face narrowly ovate to linear, 1.2–5.5 × 0.15–0.5

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[7] https://www.ville-ge.ch/musinfo/bd/cjb/africa/details.php?langue=an&id=175287 accessed on 10th March, 2021.

[8] http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:851624-1

cm., margin almost lacking, sometimes up to 1.5 mm. wide; appendages 2, terminal, filiform, the upper one (20–)30–70(–100) mm. long, the lower one (1.2–)3–10(–30) mm. long. Staminate flowers ± spaced; perianth-lobes 1–2(–3); stamens 1–2(–3). Pistillate flowers 5–10(–22), most of them in a median row; perianth tubular; stigmas 2. Staminate flowers ± spaced; perianth-lobes 1–2(–3); stamens 1–2(–3). Pistillate flowers 5–10(–22), most of them in a median row; perianth tubular; stigmas 2. Endocarp-body subglobose to tetrahedral, ± 3 mm. in diameter, at least slightly tuberculate. Forest and streamsides in woodland; 400–1350 m.

Ecology of *Dorstenia psilurus* Welw.

Evergreen forest, particularly along rivers; as ground cover in rain-forest; streamsides in woodland; sometimes forming clumps (*D. sabra*); miombo woodland; in shady or very shady parts of primitive forest, 200-1500 alt. The photo below gives a picture of the ecological requirements of *Dorstenia psilurus* Welw.

Figure 119: ***Dorstenia psilurus*** **taken at Cyamudongo**

Distribution of *Dorstenia psilurus* Welw. : The species is native to Angola, Cameroon, Central African Rep., Congo, Gabon, Malawi, Mozambique, Nigeria, Rwanda, Sudan, Tanzania, Uganda, Zambia, DRC, and Zimbabwe. In Rwanda, it was found in the primary forest at 1843.72 m alt at Cyamudongo.

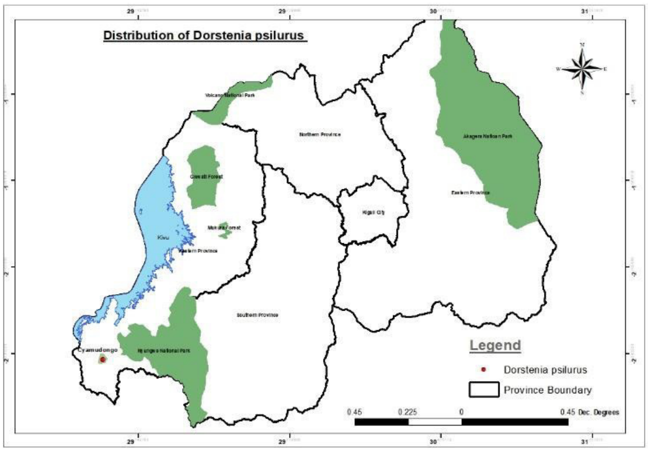

Figure 120: Distribution map of *Dorstenia psilurus* Welw

5. *Englerophytum natalense* (Sond.) T. Penn. - Sapotaceae

Synonyms: *Chrysophyllum natalense* Sond., *Pouteria natalensis* (Sond.) A. Meuse, *Chrysophyllum natalense* Sond., *Bequaertiodendron natalense* (Sond.) Heine & J.H. Hemsl., *Boivinella natalensis* (Sond.) Pierre ex Aubrév. & Pellegr., *Neoboivinella natalensis* (Sond.) Aubrév. & Pellegr., *Amorphospermum natalense* (Sond.) Baehni

Botanical description of *Englerophytum natalense* (Sond.) T. Penn[9]

Evergreen shrub or tree up to 12 m. tall, with characteristic repeated sub–apical branching. Trunk (in large specimens) somewhat fluted; bark brown, flaking. Young branchlets densely dark brown appressed–pubescent; older twigs with smooth, grey and brown striated bark. Stipules absent or very soon deciduous. Leaves tending to be clustered at branch ends. Lamina 5-16 x 2-5 cm, oblanceolate to narrowly elliptic, the apex cuspidate–acuminate, the base narrowly acute. Petiole 5–10 mm. long. Upper surface smooth, glabrous, greyish–green; midrib narrow, impressed, lateral nerves inconspicuous. Lower surface densely silvery–sericeous, mottled due to presence of scattered larger brownish hairs. Flowers solitary or in groups of 2 or 3, sessile, borne in leaf axils. Calyx 4·5–6 mm. long, narrowly ovoid, thick and leathery, deeply divided into ovate lobes but these remaining closely appressed and almost completely enclosing corolla; outer surface with brownish indumentum. Corolla 3·4–4 mm. long, whitish or yellowish; lobes 1/3–12 as long as tube, ovate, auricled at the base. Anthers 1·2–1·4 mm. long, not exserted. Staminodes 0–5, when present represented by petaloid scales c. 0·5 mm. long. Gynoecium 3–4 mm. long.

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[9] http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:962759-1 accessed on 15 March 2021.

Fruit 2–2·5 x 1–1·5 cm. narrowly ovoid to cylindrical, puberulous, deep red and edible when ripe. Seed c. 20 x 8 mm.

Figure 121: ***Englerophytum natalense*** **(Sond.) T. Penn**

Distribution of *Englerophytum natalense*

The plant was known from Cape Provinces, Kenya, KwaZulu-Natal, Malawi, Mozambique, Northern Provinces, Swaziland, Tanzania, Uganda, and Zimbabwe. In Rwanda, it was found in at Cyamudongo and Gasumo in the ranges of altitude between 1734-2064 m alt.

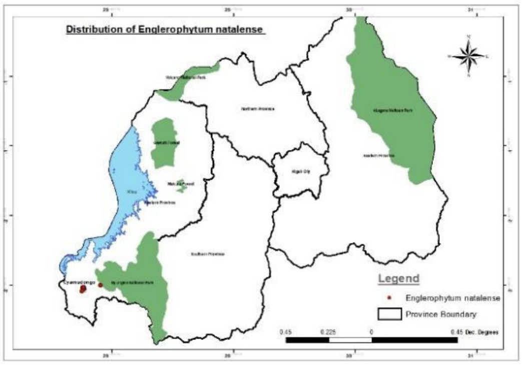

Figure 122: Distribution map of *Englerophytum natalense* (Sond.) T. Penn

6. *Aidia micrantha* (K. Schum.) F. White-Rubiaceae

The species was known in DRC, Tanzania, and Malawi and at the Eastern part of South Africa. Alt 3-1525 m as presented at the map and discovered in Rwanda, 1735-2065m alt.

Synonym(s) Homotypic : *Randia micrantha* K. Schum., *Aidia micrantha* (K. Schum.) F. White var. *micrantha*,

Synonym(s) Heterotypic: *Randia lucidula* Hiern (1898), *Randia micrantha var. poggeana* K. Schum. (1896)

Taxon infra-specific: *Aidia micrantha var. congolana* (De Wild.) E.M.A. Petit (1962), *Aidia micrantha* (K. Schum.) F. White var. *micrantha*, *Aidia micrantha* var. *zenkeri* (S. Moore) E.M.A. Petit (1962), *Aidia micrantha* var. *msonju* (K. Krause) E.M.A. Petit (1962).

Figure 123: *Aidia micrantha* (K. Schum.) F. White taken at Cyamudongo.

Botanical description: shrub ca 4 m tall; flowers in axillary clusters, often present and absent in alternate leaf axis, corolla white, hairy throat, style and inside of the tube, purple-red; fruit subspherical, Ca 1 cm in diameter, smooth, green to orange.

Ecology of ***Aidia micrantha* (K. Schum.) F. White:** The species is found in formerly disturbed area in forest (away from the river) or in disturbed secondary forest.

Distribution of *Aidia micrantha* (K. Schum.) F. White

The plant species *Aidia micrantha* was previously known in DRC, Equatorial Guinea, Cameroon and Malawi. In Rwanda, it was found at Cyamudongo and Gasumo between 1651-1783 m alt.

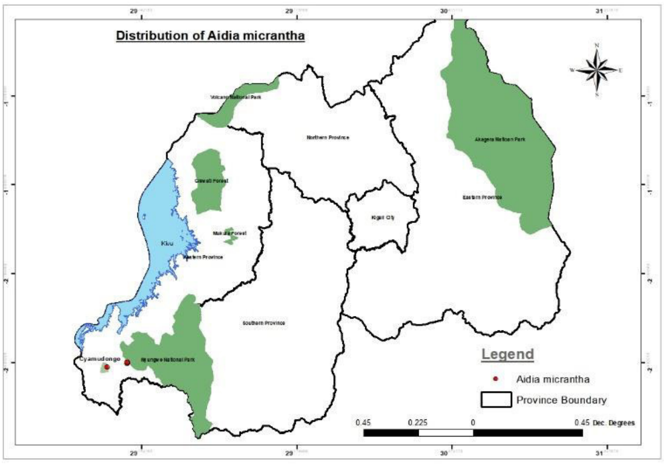

Figure 124: Distribution map of *Aidia micrantha* (K. Schum.) F. White

7. *Psychotria avakubiensis* De Wild.

Synonyms: *Trichostachys quadricuspidata* Bremek., *Psychotria comperei* E.M.A. Petit, *Uragoga setistipulata* R.D. Good, *Psychotria setistipulata* (R.D. Good) E.M.A. Petit

Botanical description: *Psychotria avakubiensis* is *a* Shrub 0.4-2m high, very white; twigs di-trichome angled, glabrous to very sparsely hairy, cylindrical, 1-2 (-3) mm in diameter. stipules green, 6-17 (-20) x2-6m, free, narrowly ovate, bifid or rarely quadrifid, with filiform to triangular lobes acute at the top of (1-) 3-13mm, shaggy at least at the base, at translucent hairs becoming reddish when dry, deciduous except at the base of the inflorescences where they persist until flowering. Leaves 0.5-2 (-4.5) cm stalked, shaggy to glabrous; blade (6-) 8-20x (2-) 2.7-10 cm, elliptical, acute at base, acuminate at apex, papery at slightly leathery, entirely shaggy to completely glabrous, dark green to medium green above and pale green below when fresh, becoming gray-green to olive brown on both sides when dry; protruding or hollow midrib on the upper surface; Lateral veins (8-) 9-13 pairs, slightly rising, united in neat arches 2-5mm from the edge; veins loose, sometimes apparent on the underside but usually very effaced; domaties and nodules absent. Inflorescences in spherical glomeruli, or rarely in thyrsis composed of 3 glomeruli, erect or more rarely hanging; peduncle of (0.4-) 0.7-5 (-8) cm, cylindrical, shaggy; flowering part 0.8-1.4 cm in diameter at flowering up to 2.5 cm in fruit; bracts null. Flowers 5-merous, heterostyled, sessile, calyx green, ciliate at the edge and sometimes scattered pubescent on the external face, with a tube of 0.5-1mm and lanceolate triangular lobes 1-5x 0.7-1.1 mm with acute or obtuse apex; corolla greenish white, with a tube of 3x1.5mm and triangular lobes of 1.5-1.8mm, glabrous on the outside, provided in the tube with a ring of white hairs at the insertion of the stamens; flower buds almost cylindrical, barely dilated and rounded at the top; stamens subincluded in longistyle flowers, with scarcely exserted filaments in brevistyle flowers; anthers cream or dark brown, 1.2x0.3mm, glabrous; ovary hirsute, 2-celled; hemispherical disc, ± 0.8 mm bifid style, exserted for 1-1.5mm in longistyle flowers, included in brevistyle flowers. Fruits green when young with sometimes paler bands, becoming bright red when ripe, ovoid with persistent calyx, smooth, shaggy or rarely glabrous, 10x8 mm, 6-9x5-7 mm when dry, sessile or pedicels very short <2 (-3) mm, accompanied by aborted ovaries which persist in infructescence; 2 grains per fruit, semi-ovoid, ± 6x5 mm, smooth on the dorsal surface; seeds smooth with a single deep ventral T-groove in cross section (Lachenaud, 2019).

Figure 125: *Psychotria avakubiensis* taken at Cyamudongo

Distribution: Lower Guinean and Congolese domain. Spread in the extreme south of Cameroon in the lower Congo then in the center of the DRC, in Burundi, apparently absent from the Congolese basin. 0-2300 m alt. In Rwanda, Cyamudongo between 1680-2087 m alt. (Lachenaud, 2019).

Ecology: Undergrowth of evergreen or semi-deciduous forest, generally on dry land, more rarely in lowlands. Locally gregarious, even dominant in the undergrowth. Normally avoids flood-prone formations along the river (Lachenaud, 2019).

Distribution of *Psychotria avakubiensis* in Rwanda

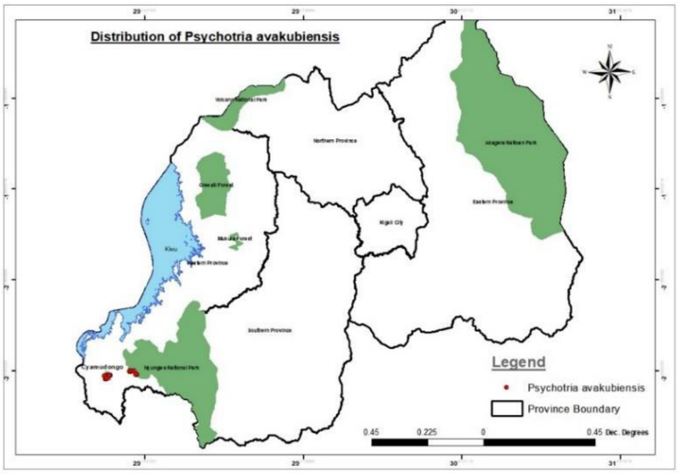

Figure 126: Distribution map of *Psychotria avakubiensis*

8. *Psychotria ceratoloba* (K. Schum.) O. Lachenaud

Synonym(s) Homotypic :*Uragoga ceratoloba* K. Schum., *Uragoga ikengaensis* De Wild., *Cephaelis ceratoloba* (K. Schum.) Schnell, Cephaelis ceratoloba (K. Schum.) Schnell.

Synonyms(s) heterotypic : *Psychotria ceratoloba* (K. Schum.) O. Lachenaud, *Uragoga ceratoloba* K. Schum. (1901), *Uragoga ikengaensis* De Wild. (1936), *Uragoga butaensis* De Wild. (1936), *Uragoga ciliato-stipulata* De Wild. (1936), *Uragoga globoso-capitata* De Wild. (1936), *Uragoga grandiflora* De Wild. (1936), *Uragoga ibaliensis* De Wild. (1936), *Uragoga isimbi* De Wild. (1936), *Uragoga lemairei* De Wild. (1936), *Uragoga lonkasa* De Wild. (1936), *Uragoga malchairi* De Wild. (1936), *Uragoga repens* De Wild. (1936), *Uragoga reygaerti* De Wild. (1936), *Uragoga semlikiensis* De Wild., (1936), *Uragoga subsessilis* De Wild. (1936), *Uragoga wendjiensis* De Wild. (1936), *Psychotria peduncularis var. ciliato-stipulata* Verdc. (1975), *Psychotria peduncularis var. semlikiensis* Verdc. (1975).

Botanical description: Very variable shrub or sub-shrub, sometimes rooting at the base, (0.2-) 0.5-3 m high; stems glabrous to shortly pubescent, cylindrical, 1-4 mm thick. Stipules pale green to bluish gray, 5-30x2-16 mm, free, ovate to elliptical, bifid up to a third or in the middle, with lanceolate to broadly triangular lobes, with a keel ± protruding at the base, pubescent at least towards the base, deciduous. Very variable shrub or sub-shrub, sometimes rooting at the base, (0.2-) 0.5-3 m high; stems glabrous to shortly pubescent, cylindrical, 1-4 mm thick. Stipules pale green to bluish gray, 5-30x2-16 mm, free, ovate to elliptical, bifid up to a third or in the middle, with lanceolate to broadly triangular lobes, with a keel ± protruding at the base, pubescent at least towards the base, deciduous. Inflorences in capitulum of hemispherical involucre, spreading ± horizontally; peduncle 0-4.5 cm, cylindrical, glabrous to shortly pubescent; flowering part 1.3-2.7 cm in diameter at flowering, 1.8-4cm in fruit; 2 (-4) pairs of free involucral bracts, green to purplish gray, elliptic to orbicular, rounded or barely pointed at the top, entire or sometimes irregularly wavy at the edge, concave or folded lengthwise ± spreading under the flower head at flowering, (4-) 5.5-12x (3 -) - 12mm, glabrous to densely pubescent, deciduous at fruiting bodies; floral bracts null or very short, linear, <1 mm. Flowers 5 (-6) -merous, heterostyly; pedicels 0-3 mm, glabrous; calyx light gray, glabrous to densely ciliate, cupuliform, with 0.3 - (- 1.5) mm tube, truncated or with spreading triangular lobes up to 1 (-2) mm; corolla white, with a cylindrical tube slightly flared at the top of the lobes, with white hairs at the top of the tube; flower buds with slightly dilated, rounded or shortly horned apex; stamens included in long-styled flowers, exserted with threads protruding from the tube for 1-2 mm in brevistyle flowers; anthers whitish, 1.2-2x0.3 mm, glabrous; ovary glabrous, 2-

celled; white disc, cylindrical, 0.3-1 mm; style bifid, exserted for 2-3 mm in longistyle flowers, included in brevistyle flowers. Fruits green when young then blue when ripe, ellipsoidal to globose, smooth when fresh, glabrous, 9-12x6-10mm when fresh, 3.5-6.5x3-5 mm when dry, pedicels accrescent white and fleshy 3.5-5x3-3.5 mm, with 6-7 well marked ribs (4-5 dorsal and 2 lateral) following the shape of the seed; seeds ribbed on the dorsal surface, provided in cross section with 2 shallow ventral furrows forming a V (Lachenaud, 2019).

Figure 127: *Psychotria ceratoloba* taken at Cyamudongo

Distribution of *Psychotria ceratoloba* (K. Schum.) O. Lachenaud

Bas-Guinean and Congolese domains, regional mosaic of Lake Victoria and Afromontane region. Spread from Southeast Cameroon to Southwest Ethiopia and western Kenya, with an area centered on the Congo Basin

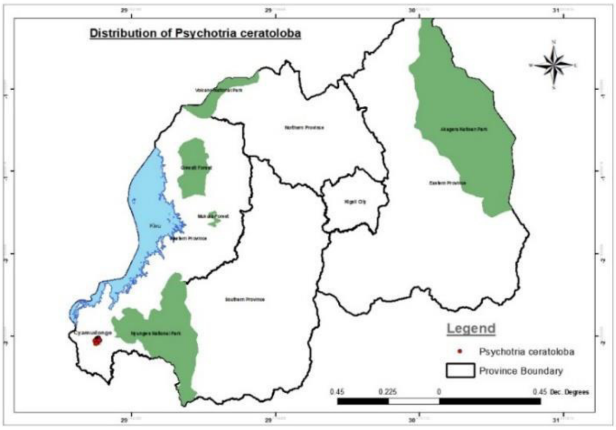

Figure 128: Distribution of *Psychotria ceratoloba* (K. Schum.) O. Lachenaud

Ecology of *Psychotria ceratoloba*: evergreen or semi-deciduous forest, forest recruits, in firm or marshy ground; 365-2175 m alt. In Rwanda, the species was discovered in Cyamudongo between 1742-2054 m alt (Lachenaud, 2019).

9. *Psychotria ealaensis* De Wild.

Synonyms: ***Grumilea ealaensis*** **(De Wild.) De Wild.**

Botanical description of *Psychotria ealaensis*

Climbing shrub with stems several m. long and attaining 3 cm. in diameter near the base, at first fairly densely covered with very short pubescence but later glabrous. Leaf-blades elliptic, 3.5–11 cm. long, 1–5.5 cm. wide, distinctly acuminate at the apex, cuneate at the base, glabrous save sometimes for some pubescence on the lower part of the main nerve beneath, thin; nodules absent; domatia present; petiole 0.2–1.5 cm. long, pubescent; stipules ovate-triangular, 4–6.5 mm. long, bilobed at the apex, the lobes 1–2.5 mm. long, pubescent or glabrous, deciduous; nodes with long hairs within the stipules. Flowers heterostylous, (4–)5(–6)-merous, in much-branched panicles 2.5–10 cm. long; peduncle 1–4 cm. long, glabrous or pubescent; secondary branches 0.2–1 cm. long, pubescent; pedicels obsolete or ± 1 mm. long, very shortly pubescent; main bracts ± 3 mm. long, lobed at the base, clasping the stem, rest small, ± pubescent. Calyx-tube conic, ± 1 mm. long, glabrescent; limb cupuliform, 0.75–1 mm. long, glabrous or sparsely covered with very short almost papilla-like hairs; lobes very short, broadly triangular, ± 0.5 mm. long. Corolla yellowish, greenish or lilac, glabrous to finely densely tomentose outside; tube 3.25–5.5 mm. long; lobes ovate-triangular, 2–2.5 mm. long, 1–1.5 mm. wide. Stamens purple, with filaments 2–2.5 mm. long in short-styled flowers, 0.5–0.75 mm. long in long-styled flowers. Style 1.5–3 mm. long in short-styled flowers and 4–5 mm. long in long-styled flowers; stigma-lobes 0.75–1 mm. long. Drupes red, ellipsoid, 5–7(–10 in living state) mm. long, 7(–8) mm. wide, with 2 pyrenes; pyrenes depressed semi-ellipsoid, 5.5 mm. long, 4.2 mm. wide, 2.5 mm. thick, ventral face plane, dorsal face obscurely ribbed. Seeds dark blackish-red, of similar shape, 4.5 mm. long, 4 mm. wide, 2 mm. thick, ventral face rugose, dorsal face irregularly 7-ribbed; albumen ruminate on both faces but particularly between the dorsal ribs[10].

Figure 129: Specimen of *Psychotria ealaensis* collected from Cyamudongo

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[10] http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:761934-1 accessed on 10th May 2021.

Synonym(s) Homotypic: ***Grumilea ealaensis*** **(De Wild.) De Wild.**

Distribution***:*** *Psychotria ealaensis* is native **of** Cameroon, Congo, Gabon, Ivory Coast, Malawi, Mozambique, Tanzania, Uganda, and DRC. Range of distribution: 1110-1500 (–2050) m. In Rwanda, the species was recorded at Cyamudongo between 1871-1967 m alt.

Distribution of *Psychotria ealaensis* in Rwanda

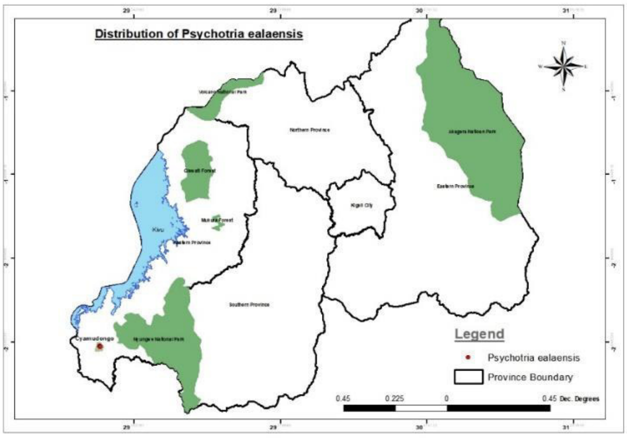

Figure 130: Distribution *Psychotria ealaensis*

10. *Psychotria nigropunctata* Hiern

Synonym(s) homotypic: *Myrstiphyllum nigropunctatum* (Hiern) Hiern, *Uragoga nigropunctata* (Hiern) Kuntze.

Figure 131: *Psychotria nigropunctata* taken at Cyamudongo

Botanical description: *Psychotria nigropunctata* is a shrub very variable in habit, erect or rhizomatous (0.1-) 0.3-1.5 m; stem glabrous or puberulous, cylindrical, 1-1.5 mm thick, stipules green, 3-6 x 1-2mm, free, bicuspid with triangular base and filiform lobes of 1.5-3 mm, glabrous or pubescent, caduceus. Leaves with petiole with 0.2-2.5 cm, glabrous or puberulous; blade 4-14 x 1-5 cm, elliptical, acute at the base and decurrent on the petiole, gradually acuminate at the apex, papery, sometimes wavy at the margin, glabrous or perulent on the underside of the veins, dark green above and pale green slightly pearly below when fresh, remaining green or blackening when dry; midrib protruding from the upper side; lateral veins 6-11 pairs, rather ascending, united in little visible arches 1-2 mm from the edge; veins loose and inconspicuous, domatia absent; nodules dispersed in the lamina, of very variable shape and dimensions (round, linear, or lobed), quite dense (12 to 50 / cm^2) and very apparent. Inflorescences in simple umbels or more rarely in thyrses composed of 3 to 5 umbels, hanging in fruit or often from the flowering (Lachenaud, 2019).

Distribution Psychotria nigropunctata Hiern

The species was known from the Bas-Guinean and Congolean domains. Spread here and there from Gabon to northeastern Angola and eastern DRC; common in the lower Congo, elsewhere generally quite rare

Ecology: Undergrowth of evergreen or semi-deciduous forest, in firm or marshy ground, 90-1450 m alt. in Rwanda identified at Cyamudongo in more or less disturbed areas, 1873-2018 m alt.

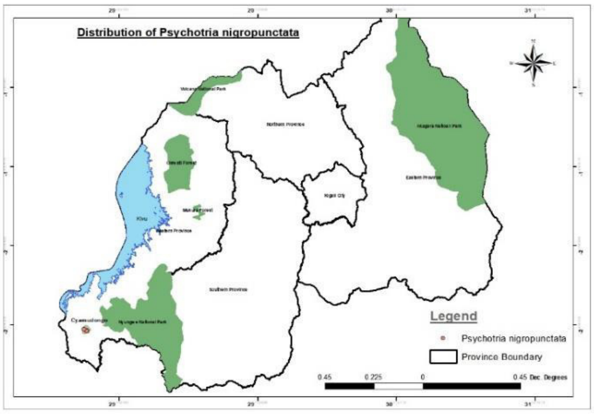

Figure 132: Map of Psychotria nigropunctata

11. *Psychotria punctata* Vatke

Synonym homotypic: *Psychotria punctata* Vatke *var. punctata, Apomuria punctata* (Vatke) Bremek., *Uragoga punctata* (Vatke) Kuntze

Botanical description: Shrub or small tree; Leaf-blades elliptic to ovate-elliptic, 3–13 x 1–6 cm, usually obtuse at the apex; bacterial nodules visible as numerous scattered dark dots; petioles up to 2 cm long; stipules ovate-triangular, 2–3 mm long, entire or ± bifid at the apex, ± persistent; flowers 5-merous, in rather dense pedunculate panicles; bracts obsolete; calyx with a cup-like limb; lobes obsolete; corolla white; tube 3.5–5.5 mm long; lobes 2.5–3.5 mm long; drupes red, subglobose, 5–6 x 6–9 mm; seeds with entire endosperm[11].

Figure 133: ***Psychotria punctata*** **taken at Cyamudongo**

Synonym(s) Heterotypic

Psychotria bacteriophila Valeton, P*sychotria beniensis* De Wild. , *Psychotria hirtella* Oliv., *Psychotria kirkii* var. *hirtella* (Oliv.) Verdc., *Psychotria kaessneri* Bremek., *Psychotria swynnertoni*i Bremek., *Psychotria kirkii* var. *swynnertonii* (Bremek.) Verdc., *Psychotria collicola* K. Schum., *Psychotria tarambassica* Bremek., *Psychotria kirkii* var. *tarambassica* (Bremek.)Verdc., *Psychotria mucronata* Hiern, *Uragoga mucronata* (Hiern) Kuntze, *Psychotria kirkii* var. *mucronata* (Hiern) Verdc. , *Psychotria maculata* S. Moore, *Psychotria marginata* Bremek. , *Psychotria melanosticta* K. Schum. , *Psychotria nairobiensis* Bremek., *Psychotria kirkii* var. *nairobiensi*s (Bremek.) Verdc. , *Psychotria ciliatocostata* Cufod., *Psychotria pachyclada* K. Schum. & K. Krause, *Psychotria petroxenos* K. Schum. (1907), *Psychotria pubifolia* De Wild., *Psychotria punctata* var. *minor* E.M.A. Petit, *Psychotria punctata* var. *hirtella* Chiov., *Psychotria punctata* var. *tenuis* E.M.A. Petit , *Psychotria rutshuruensis* De Wild., *Psychotria subhirtella* K. Schum., *Psychotria volkensii* K. Schum., *Psychotria kirkii* var. *volkensii* (K. Schum.) Verdc., *Psychotria kirkii Hiern* var. *kirkii, Psychotria kirkii* Hiern, *Uragoga kirkii* (Hiern) Kuntze.

Botanical description of *Psychotria punctata* Vatke

Shrub or sub-shrub very variable in habit, erect or rhizomatous, 0.3-4 (-6) m high, with donut bark to light gray or more rarely dark brown; cylindrical stems 1-3mm thick, glabrous or densely tomentose with short hair (<0.3mm) and ± spreading. Stipules green more rarely whitish, 3-7x1-4.5 mm, free, bicuspid, with a ± triangular base and 0.5-3 mm linear lobes, glabrous to puberulent, deciduous or marcescent. Leaves 0.1-3 (-4) cm stalked, glabrous to

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[11] http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:763141-1 accessed on 15th May 2021.

densely pubescent; blade 3.5-21.5x1.5-10.4 cm, ovate to obovate, acute at the base and clearly decurrent on the petiole,

obtuse to shortly acuminate at the apex, papery to leathery, sometimes thickened and whitish margin, glabrous to densely tomentose on both sides, dark to medium green above and pale green below when fresh, becoming greyish to blackish when fresh dry; variable midrib, hollow or slightly protruding on the upper surface; lateral veins 5-10 pairs, strongly ascending forming at an angle of 30 to 60 degrees with the median, united in inconspicuous arches 0.5-3.5 mm from the edge; veins loose and inconspicuous; domaties absent; nodules scattered in the leaf blade, round and quite small, 0.1-0.5 mm in diameter, rather sparse (4 to 20 / cm^2), generally very visible. Inflorescences in thyrses with umbellulate branching at the top, or sometimes in simple umbels, erect or pendulous, 1.8-9.5 (-15) cm, glabrous to densely pubescent; peduncle 0.9-5.5 (-9.5) cm, cylindrical or slightly bicostate; flowering part of 0.7-4.5 (-5.5) x1.1-5 cm; branches zero or 2 (-4), up to 2.5 cm; bracts very small, <1.5 mm. Flowers 5-merous, heterostyle; pedicels of (0-) 1-3 mm. hairless to sparsely pubescent; cup-shaped, with a 0.5-1.2 mm tube, barely angular edge, or sometimes with irregular triangular lobes up to 1 mm; corolla white to yellowish green, with narrow and almost cylindrical tube 3-5.5x0.8-2 mm and triangular lobes of (1-) 1.5-3 mm, glabrous on the outside, provided in the tube with a dense ring white hairs at the insertion of the stamens; flower buds almost cylindrical with a rounded top; stamens included in longistyle flowers, exserted with threads protruding from the tube on (0-) 1.5-1 mm in brevistyle flowers; anthers white, 1-1.2x 0.3-0.5 mm, glabrous; ovary glabrous, sparsely pubescent, 2-celled; whitish, hemispherical disc, ± 0.4 mm; bifid style, exserted for 1-2 mm in longistyle flowers, included in brevistyle flowers. Fruits dark green when young then bright red when ripe, globose or a little wider than long and often ± bilobed when dry, smooth, hairless, 4.5-10x4.5-11 mm when dry, with often persistent calyx and pedicels of 2-3 mm, 2 stones per fruit, hemispherical, 3-4x3-4 mm, smooth on the dorsal surface; seeds smooth, with a deep ventral T-shaped groove in cross section (Lachenaud, 2019).

Distribution of *Psychotria punctata* Vatke

Widespread and abundant in eastern Africa from Ethiopia to Mozambique, reaching eastern DRC, and extending north-west to Chad and the Central African Republic where it is rare; also on the island Mayotte. In Rwanda, it was found between 1781-1936 m alt.

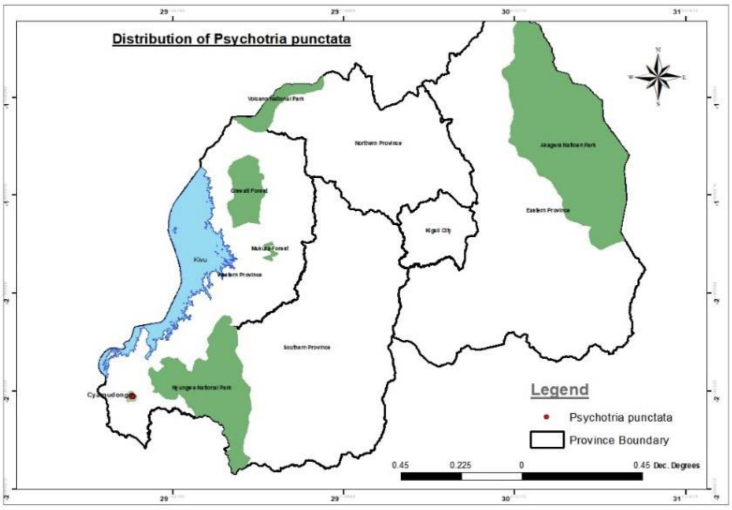

Figure 132: Distribution of *Psychotria punctate*

12. *Leptoderris burundiensis* Bamps & Champl.

Botanical description

Sarmentous shrub or liana 2--15 m long, with dark brown bark, provided with lenticels. Leaves imparipinnately compound, with triangular stipules 3 x 4 mm; 5 leaflets obovate, truncate to retuse and apiculate at the top, sub-rounded at the base, 4.7--17 x 3--8 cm, densely tomentellose-greyish or whitish on the underside, glabrous above; stipels c. 1 mm, early caducous; lateral veins (5 -) 6--8, depressed above, very prominent below, veins very prominent; rachis 8--16 cm long, petiole thickened at base, about half of rachis; petiolules 2.5--8 mm long. Inflorescence in panicle with spike-like branches, few in number; flowers inserted on short lateral axes 0.5--1.5 cm long subtended by small deciduous triangular bracts 2.5 mm long; pedicels 0.5--1 mm in length; all the tomentellous axes; calyx densely pubescent, dark brown, with a tube 4--6 mm long, terminated in 5 very short teeth, surrounded at the base by bracteoles about 2 mm long; corolla glabrous, yellow to greenish-yellow sometimes washed with pink, 11--14 mm long; petals ciliolate; standard broadly obovate, cymbiform, 8--10 x 7--10 mm; keel 8--11 x 5--6 mm; wings absent or adnate to the keel and 7--8 x 2--2.5 mm; staminal tube glabrous, 7--9 mm long, with an opening at the base leaving free the lower part of the vexillary stamen fillet, this free part welded on the lower ½ of its length to the standard; top free part of filaments of stamens 3--4 mm long; anthers 1 mm long; ovary densely pubescent, 8--9 mm long; style 4mm long, curved. Pods oblong, papery, pubescent, mucronate at the top, 7 x 2 cm, with a unilateral wing 4 mm wide at its mid-length. One seed per pod (Bamps & Champluvier, 2012).

Figure 133: ***Leptoderris burundiensis*** **taken at Cyamudongo**

Distribution: Native range is E. Central Tropical Africa (Burundi, Rwanda, and DRC*). L. burundiensis* is endemic to the Congo-Nile ridge in Congo, Rwanda and Burundi, where it grows between 1700 and 2400 m altitude. In Cyamudongo, the species is found between 1870 and 1906 m alt (Bamps & Champluvier, 2012).

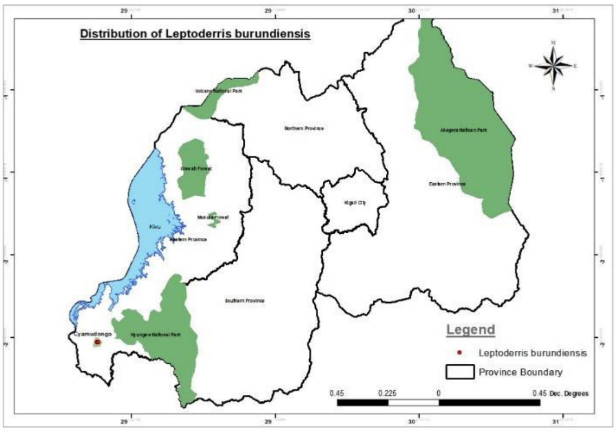

Figure 134: Distribution map of ***Leptoderris burundiensis*** **in the study area.**

During the research period, several other records couldn't be assigned their full scientific names. For instance, the following taxa were not identified at the species level and were suspected to be new records: *Agelaea sp.* (Connaraceae)*, Pristimera* sp.(Celastraceae), *Flabellaria sp* (Malpighiaceae), *Synsepalum* sp. (Sapotaceae), *Ceropegia sp* (Apocynaceae), *Coffea sp* (Rubiaceae), *Vitex sp.* (Lamiaceae), *Leptaulus sp (*Cardiopteridaceae), *Ochna sp* (Ochnaceae). Families of Orchidaceae, Acanthaceae, Sapindaceae (*Allophyllus*), Moraceae (*Ficus*) require further and detailed research for identification of several of their members recorded in this study.

5.5 Species diversity

The species richness was claimed to be the dominant measure of biodiversity and its changes (Hillebrand *et al*., 2018) and patterns of species richness, composition and abundance are the net results of species dynamics, i.e. recruitment, growth and mortality, and the subsequent population changes of species composition (van Breugel, 2007).

Alpha diversity

Gallery (2016) hypothesized that α-diversity may be more strongly controlled by stochastic and biological processes such as disturbance and especially pressure and specialization of pests on locally abundant hosts. The initial survey under this study showed a moderate similarity among the buffer zone and the secondary forest landscapes of Cyamudongo and Gasumo with almost a same interval in terms of species richness which was found higher than the primary forest landscape. With reference to the classification of the studied communities as, changed, highly and moderately disturbed habitat, the higher α-diversity attributed to buffer zone, secondary forest and Gasumo landscapes revealed a high level of disturbance.

In a previous study, the plant species diversity was found to be higher in primary forest than in fragmented forests and the more the level of the disturbance increase, the more the species richness decline (Zhu *et al*., 2004). This statement contrast Shwe Zin & Mitlöhner (2020) where deforestation due to logging created gaps which favor new species and increased species diversity and is consistent with the finding of this study where the species richness has been higher in buffer zone, secondary and Gasumo forest than in primary forest landscape at the initial phase.

This result is in agreement to the finding of Vetaas *et al.* (2020) that in area with low to almost no disturbance herbaceous species richness has declined, whereas the woody species have increased, and vines remain the same and species richness and community composition have been found influenced strongly by the secondary forest age (Goosem *et al*., 2016).

The similarity between different forest landscapes is due to the fact that most of the species in the buffer zones are also found in the secondary forest except exotic species such as *Pinus patula, Grevillea robusta, Maesopsis eminii*, *Eucalyptus sp…* The high species richness in plots of buffer, secondary and Gasumo at the starting phase of the study was referred to the extensive and frequent human disturbance as proposed by Williams in Van Andel (2001). This corrabote with observation obtained during the survey with regular tree logging, fuel wood and non-timber products collection by surrounding communities both at Cyamudongo and

Gasumo. A previous study on secondary forest concluded support the same finding that the deforestation due to logging, created gap openings that favor new species and increased the species diversity, even higher than the primary forest (Shwe Zin & Mitlöhner, 2020).

It was also, found that the seasonal variation impact the species richness as distinct rainy and dry seasons drive plant phenological response where the mean annual rainfall is lower with dry season months characterized by greater evaporative potential than precipitation (Gallery, 2016). In this contex, it occurred a change in species richness from the initial to the intermediate phase where there has been increase and heterogeneity in species number composition in the buffer zone, secondary forest and Gasumo landscapes while the α-diversity decreased in the primary forest in the period of short rain season 2019. On the other hand, findings of the final phase of the sudy illustrated the effect of the seasonal variation during the dry season with a general decrease of α-diversity in primary forest and buffer zones dominated by the secondary forest and Gasumo ones. These finding were found in agreement with Kreutz *et al.* (2016) who asserted that the he seasonal variation in species richness and abundance was related primarily to the reduction in humidity during the dry season and with a seasonal dynamism in species richness suggested by Hillebrand *et al.*(2018). The more or less heterogeneity with higher species within landscapes mostly in buffer zones, secondary forest and Gasumo should be associated to environmental heterogeneity and associated variation in microclimatic conditions, and account for the higher species richness and diversity with exclusive species to these environments. The same, higher environmental homogeneity predict lower species richness and explain the lower α-diversity that occurred in the primary forest landscape with more consistent groups of species, with well-defined similarities as supported by Kreutz *et al.*(2016).

Beta diversity

According to Hill & Hill (2001), ß-diversity describes between habitat diversity or species turnover and environmental gradients. Greater ß-diversity reflects greater spatial variation in geology, climate, and delay in forest recovery after temporal variation (Duivenvoorden *et al.*, 2002) and allow to concepts what controls the diversity in ecological community. Species turnover reflect deterministic processes, such as species' adaptations to differences in climate or substrate, or it can result from limited dispersal coupled with speciation, delayed response to climatic change, or other historical effects. Perhaps more important, beta-diversity is as important as alpha-diversity for conservation, because species turnover influences diversity at large scales as stated by Condit *et al.*(2002). The findings of the study showed that the global beta-diversity of the initial phase of the study was higher than ones of the following study phases and a high global beta-diversity impact community visualization using different ordinations methods according to McCune & Grace (2002). ß-diversity values found were greater than 6, most of the communities overlapped and hinder their visualizations. The β – diversity decreases, increases or remains unchanged impacted by human activities depending because of the balance of the process that cause biotic heterogeneization or homogenization between sites and during the initial stage of anthropogenic impacts, localized species are lost and invader are established causing increase of ß-diversity (Socolar *et al.*, 2016).

Even though, communities are overlapping, ß-diversity varied among landscape studied and phases of the study. It is believed that more an ecological assemblage made of distantly related taxa is more diverse than an assemblage composed of closed related taxa according to Clarke & Warwick in Desrochers & Anand (2003). Findings showed that ß-diversity of the initial phase of the study was higher in all landscapes and decreased with succeeding phases with very little difference meaning that a high level of dissimilarities within and between assemblages of landscapes under study. This is in agreement with the definition attributed to beta diversity as the spatial turnover or change in the identities of species and a measure of the difference in species composition either between two or more local assemblages or between local and regional assemblages. It was argued that for a given level of regional species richness, as beta diversity increases, individual localities differ more markedly from one another and sample a smaller proportion of the species occurring in the region (Koleff *et al.*, 2003). In fact, α-diversity discussed previously pictured kinds of heterogeneity in species richness which may be referred to different environmental conditions, seasonal variations and disturbances that should had impacted beta diversity of the buffer zone, primary and secondary forest as well Gasumo. Socolar *et al.* (2016) added at the point when human effects are sketchy in space, beta-diversity is probably going to increment at the scene and argued that numerous human activities are a dominant engine for communities' distinctions and other negative impact.

Plant species evenness and relative abundance among study landscapes

In ecology, the evenness quantifies the homogeneity of species abundances (Beisel *et al.*, 2003). The finding of the study showed that the evenness trends showed distinct patterns for forest landscapes under study for different periods of the study. Even though, the evenness was high at all research phases; the buffer zone, the secondary forest and the second phase of the primary forest and Gasumo landscapes showed a high level heterogeneity while a good level of homogeneity appeared at the initial and final phases of the primary and Gasumo landscapes due distribution of species relative abundances suggested by Beisel *et al.*(2003). This gives means to confirm that the phytocoenose of the primary forest and Gasumo landscapes were more even than the ones of the buffer zone and the secondary forest landscapes of Cyamudongo.

Differences in evenness trends from one phase to another are supported in previous literatures and originate differently. For instance according to Dorji *et al.*(2014), plant community properties such as species richness, evenness (abundance equality of species) and composition affect key ecosystem functions and stability and it has been established that species evenness is increased with soil moisture at low elevation and decrease with soil moisture at high elevation. Additionally, the variation of community evenness may be to a large extend associated to the spatial variation of the abundance of dominant species. Furthermore, the relationship between species richness and evenness depend on ecological processes such as competition, predation, and succession which alter the proportional diversity (Zhang *et al.*, 2012). In the same way, evenness difference observed between landscapes could be due to the very dynamic nature of different habitats experiencing disturbance that increase habitat heterogeneity, propagule arrival and colonization and plant community response to disturbance would vary depending habitat stability (Biswas & Mallik, 2010). High evenness and variable patterns in changed or highly disturbed habitats can be understood to vary more strongly along a disturbance gradient as testified as Mackey & Currie (2000).

Moreover, almost similar trends were found for the initial and the final phase of the study, periods following the long dry season where the evenness trend lines showed indices as they are indications of equitable distribution pattern among individuals of species within plant communities in the forests landscapes studied. All trends showed almost closer species evenness as in agreement with the statement that the no significant discrepancy of the overall species evenness should mean that communities studied may be exposed to similar environmental conditions (Mligo, 2018). The effect of weather on species evenness has been manifested with the intermediate phase of study where evenness trend lines showed more heterogeneity and inequitable distribution pattern among individuals within plant communities. This agree with Chapungu & Nhamo (2016) who point out the increase in temperatures is leading to changes in species richness and species tolerance to environmental gradients such as temperature vary depending on the type of species but, some species can cope with changing temperature patterns by adapting themselves to the new conditions in their local range, rather than by tracking their current optimal conditions in space or time.

Simpson diversity index

The results of this study show that the diversity changed among studied landscapes and phases of the study. More degraded habitat displayed trends lines patterns with more heterogeneity in species diversity while landscapes with moderate disturbance, trend lines tend to be more homogenous. This agrees with the statement that environmental factors such as disturbance, landscape cover, climate, account for the variance of the components of biodiversity (Sebastia *et al.*, 2006). The upper diversity indices obtained indicated more or less uniformity of the plant diversity composition with patterns of homogenous trend lines with high diversity at the final phase of the study for all landscapes. The primary forest and Gasumo had showed similar patterns on trend lines almost stable with a little variability among all research phases. This finding is similar the positive relationship between diversity and stability obtained from a -11 year study and the variability correspond to the degree to which plant species respond differently to climate variability (Orians, 2000). The high Simpson indices in the buffer zone landscape of Cyamudongo found is as a condition for the biological diversity requirements (Arthur Ebreg &Pol de Greve, 2000) to be high as much as possible and where the conditions and structure of the vegetation and landscape of the buffer zone should preferably be as similar as possible to that of the conservation area, as if the buffer zone is an extension of the core zone. In this areas, the natural vegetation is recovering through natural regeneration and will probably reduce the rate of climate change, to recover biodiversity, and in turn, return the provision of ecosystem services and rural livelihoods to degraded landscape as granted by Hethcoat *et al.* (2019).

Diversity patterns and ecological process description using Shannon index

Shannon index has been shown to be useful to quantify the landscape composition emphasizing on the richness components of the diversity (Nagendra, 2002). The results of the study have shown varying degrees of richness among landscapes studied and period of the study. An increase in richness component of diversity reaching almost a same range between 2.0 and 3.0 has been achieved in the buffer zone landscape and was found higher than in secondary forest landscapes. The result agrees with Kermavnar *et al.*(2019) that diversity metrics (species richness, total cover, Shannon index) increased in plots where the silvicultural measures were applied and canopy when compared to uncut controls plots hosted a higher number of colonizing species with higher plant height and small seeds. In primary forest, a slight decrease of the diversity during the short rain season was followed by a pattern almost at equilibrium with an increased species diversity. Although, Gasumo landscape, has been more heterogeneous with a higher range of diversity compared to other landscapes. This is the line with Halpern & Spies (1995) who pointed out that following canopy closure, vascular plant diversity tend to increase with time, peaking in old growth, few understory species are restricted to or absent from, any stage of stand development (i.e young, mature or old growth).

5.6 Similarities among Cyamudongo landscapes and the study of Gasumo

The PCA finding shows that landscapes studied are not clearly separated from each other as they all share some similarities to each other and in common. The dominating feature of the initial phase of the study, except for the primary forest was entirely the secondary forest nature as depicted on figure due to disturbances. In these landscapes some areas mostly the buffer zones, the secondary and Gasumo forest were or continue to be heavily subjected to anthropogenic disturbances in combination with natural disturbances as suggested by Gibson (2002) and affecting plant populations. These landscapes were defining at that step a spatial heterogeneity proposed by the same author where the primary forest was less affected. In this spatial heterogeneity, Gasumo study are and the buffer zone landscapes were included in Secondary forest landscape. It assumed that the partial disturbances enhance spatial heterogeneity through the diversification of forest structure, which contributes to niche partitioning and consequently to species diversity. However, this heterogeneity–diversity relationship may differ between groups of species, and is potentially modified by biotic interactions at the community level as stated by Markgraf *et al.* (2020).

A little change in the spatial heterogeneity of landscapes studied occurred where the buffer zone is more discarded than other. But the impact of disturbances was again reflected the areal extend shared by the secondary forest. The commonness of these landscapes which share much of their disturbed extent, are known to share lower tree diversity and greater shrub diversity in the same landscapes due to biotic interactions of shrub competition as asserted by Markgraf *et al.*(2020).

At the final phase of the study, the landscape spatial heterogeneity persist and the impact of the disturbance reduced and more reflected in buffer zone Gasumo while the primary forest discarded more. This showed how in different landscapes, are spatially distributed resources and determined the quality of the habitat. In this context, forest habitat mosaics may be more affected by lack of heterogeneity than by structural fragmentation. Nonetheless, increasing spatial heterogeneity at a given spatial scale can also decrease habitat patch size, with potential negative consequences for specialist species and break the relationship diversity and heterogeneity (Redon *et al.*, 2014).

5.7 Landscape communities and biotic and abiotic interactions

As discussed above, the forest landscapes of Cyamudongo and Gasumo studied were found having similarities mostly related to disturbance as demonstrated by the principal components analysis and species overlapped more within the community (an increase in functional overlap) leading to habitat filtering as defined by Li *et al.* (2018). The high disturbance can lead to abiotic filtering, generating a community dominated by closely related species with disturbance-adapted traits where biotic interactions play a relatively minor role (Ding *et al.*, 2012). Before fragmentation the entire forest was initially a primary forest for many years ago before human intervention that fragmented the forest. The CA Figure showed that all forest landscapes had a big similarity with secondary forest, except portions of primary forest and Gasumo discarded. The occurrences of common species may have resulted from habitat filtering and reduction in canopy and consequently the growing of many species whose characteristics of taking advantages leading to the increase in beta diversities (Socolar *et al.* 2016).

The impact of weather has been identified through research periods with the decrease of landscapes overlaps after the short rain season on the intermediate study in 2019. It was found that the biotic and abiotic filters such us plant species, sunlight, rainfall, canopy cover, altitude differentially influenced trait organizing along environmental gradients. Similar shapes refer to individuals with similar stress-tolerance trait values, and the level of shading refers to relative combative ability of these individuals, with lighter individuals being less combative. On passage through the abiotic filter, stressful conditions reduce the survival and combative abilities of the most combative species, with negligible effects on the stress-tolerant species as highlighted Ding *et al.*(2012). Additionally, the decrease of the overlap has been facilitated by dominant plant mostly light competitors. In this sense, *Acalypha psilostachya* and *Acalypha neptunica* are associated positively to secondary, the buffer zone and the secondary forest with the longest amplitude extended on the first principal components. The role of lianas in the structure and composition of communities is well known. *Acacia montigena, Urera hypselodendron, Dalbergia lactea* shaped the community structure with a negative impact and a decrease of the general diversity in the secondary forest, primary forest and Gasumo landscapes mostly. The liana behavior has been described and this finding is in agreement with Campanello *et al*. (2007) on the idea that appear to inhibit tree regeneration by changing environmental conditions. In the same line, according to Schnitzer and Strong in Tang *et al*., (2012), lianas play an important role in forest population dynamics. They constitute the baseline levels of plant diversity in forests and maintain tree diversity through their role in gap dynamics. A high liana load in tree canopies may cause high tree-fall rates, thus maintaining rainforests in a perpetual disclimax and thereby potentially maintaining diversity by reducing the level of dominance among tree species. The first and the 3rd phase of the study have been almost similar with differences in species in species dominance and distribution among communities where drivers of grouping remained the same with *Acacia montigena* affecting negatively species diversity except in the primary forest where its presence has a negligible effect on the landscape. Moreover, the short rain season decreased more the overlap. The buffer zone and the secondary forest were more diverse and not dominated by *Acacia montigena* by contrast with the primary forest and Gasumo where its occurrence affect negatively the diversity as causing damages of host trees and reducing their growth rates (Addo-Fordjour *et a*l., 2013).

5.8 Environmental factors and forest communities structure

From ecological theories, multiple environmental factors shape local species assemblages by progressively filtering species from the regional species pool to local communities (de Bello *et al.*, 2013). The structure of a plant population is a function of a combination of biotic and abiotic factors such effects of neighbors, manipulating reproduction, herbivory, pathogens, allelochemicals, soils nutrients and moisture, temperature, light, atmospheric changes including ultra-violet light, and disturbance regimes (Gibson, 2002). In the three phases of the study, all landscapes studied were influenced by environment factors leading to new shape of the flora community. The disturbance has been found to be the important engine of communities' composition structure. During the period of the study, a positive effect along the disturbance gradient was more prevalent in the buffer zone and the secondary forest with increase of the species diversity while at the other hand, the impact was negative for the primary and Gasumo. This is supported by Dornelas (2010) who, from his research pointed out the existence of the positive and negative effect of the disturbance. In the buffer zone and the secondary forests, more specialized species tend to grow in these landscapes with indicator species hidden in the cloud. A combined effect of the vegetation cover and *Acacia montigena* affected negatively Gasumo and the primary forest with reduction in species diversity while the combination of the disturbance and the *climbing Acacia montigena* affected negatively the secondary with a decrease of the diversity as asserted by (Takafumi, & Hiura (2009) that the combination of natural and anthropogenic disturbance affects the diversity and functions of understory plants. As the studied communities ranged between from 1685 to 2122 m alt., it was found that the diversity in lower altitude with no or low disturbance was more likely to belong to a same community with similarity in species composition and clouded in the center. The effect of altitude on species diversity has been demonstrated Chawla *et al.*(2008). Authors highlighted that the effect of increasing altitude is quite evident on both the family and species richness and the herbaceous species dominated the entire altitudinal gradient in terms of species richness, and with increasing altitude the trees and shrubs got disappeared. The effect of altitude on species diversity displays a hump-shaped curve which may be attributed to increase in habitat diversity at the median ranges and relatively less habitat diversity at higher altitudes.

5.9 Communities clusters and indicators species

A multivariate analysis by clustering analysis with Manhattan similarity allowed to find grouping of variables or associations in the data set of the tree phases of the study (Hammer *et al.*, 2009). According to Parks & Beiko (2012), environmental drivers of biodiversity can be identified by relating patterns of community similarity and the variation of community has been evaluated by taking in to account changes in species composition and the phylogenetic information was incorporated to account for the relative similarity of taxa. The findings of the study showed changes in spatial patterns of the distribution of communities under study and among study periods where cluster groups and composition varied. These changes can be assumed to be under the control of internal (e.g., population dynamics and external (e.g., environmental characteristics) driving forces as well as current and stochastic events (Legendre & Legendre, 2012).

Initially, only two cluster groups were almost more distinct with high abundance of plant and species richness. In the clustering pattern, the break between groups was not clear, thereby making sub-communities not distinct from each other from an undifferentiated spatial association as defined by Batlle & Van Der Hoek (2018). Clusters differentiation may depend on gradual variation and interactions of environmental conditions, including temperature, precipitation, light, and soil resulting in increase of the geographic distance between populations (Pritchard & Anderson, 1971).

The Cluster groups A (CGS) was made of communities from all landscapes with dominance of few species known to be common in a specific type of forest. *Elaeodendron buchananii*, *Pancovia golungensis trees* from primary forest, *Boehmeria platyphylla, Justicia scandens, Piper umbellatum, Solanum chrysotrichum,* and *Mussaenda arcuata* fast growing species or of invasive behavior from the buffer zone and secondary forest with several other forest species of low amplitude of dominance such as *Ixora burundensis, Hippocratea apocynoides, Dioscorea sp, Grewia sp., Harungana montana* and *Asplenium mannii.*

The cluster group B collected subgroups of different landscapes and different life forms such as trees, lianas and epiphytes dominated by *Agelaea macrophylla, Acacia montigena, Thunbergia vogeliana,* trees such as *Trilepisium madagascariense, Celtis gomphophylla, Symphonia globulifera, Carapa grandiflora*, *Asplenium gemmiferum, Asplenium sandersonii* and terrestrial ferns. The variation of floristic composition and forest structure is attributed to the degree of disturbance in the study area. In this community, the indication of the disturbance is exemplified by the common species growth in secondary and disturbed forest (Adam *et al.*, 2007) such as *Polyscias fulva, Carapa grandiflora, Macaranga kilimandscharica, Musanga leo-errerae, Myrianthus holstii and Newtonia buchananii* (Fischer& Killmann, 2008). Even though, the forest experienced changes due to disturbance, the floristic composition with broadleaf trees with a closed canopy usually composed of high diversity of tree species correspond to tropical moist forest including lowland evergreen rainforest, lower and upper montane rainforest, health forest (Whitmore, 1990; Thomas & Baltzer, 2002) and with large buttress supporting climbers, epiphytes and hemi-epiphytes and a multi-layered canopy as argued Zakaria *et al.*(2016).

During the intermediate and the final surveys, more cluster groups have detected and the break between groups was most clear and groups have been distinct from each other. Clusters were found different in species composition and abundance. Among them, the pattern showed a close similarity between the Gasumo landscape and the primary forest of Cyamudongo and characterized by natural forest dynamics in tree composition with occurrence of dead wood and a natural regeneration process as stated by FAO in Kormos *et al.* (2017) and provide refuge to endemic. Indicator species have been high canopy tree species such *Elaeodendron buchananii, Magnistipula butayei, Trilepisium madagascariense, Entandrophragma excelsum, Chrysophyllum gorungosanum* as suggested by Caroline *et al.*(2016) that primary forest plots were characterized by Phanerophytes. The close proximity of the homogenous or mixed buffer zone with similarities to primary forest landscape forest signified a semi-natural forest where the natural regeneration is being achieved through the silvicultural techniques including planting and seeding native species of as pointed out Schuck *et al.*(1989).

The research finding has showed that the floristic composition and the life-forms in cluster groups depended mostly on their landscape components where indicator species of clusters close to the secondary forest are characterized by Geophytes and Chamaephytes, able to propagate vegetatively and resist disturbances (Caroline *et al.*, 2016) such as *Pteris pteridioides, Pteris dentata, Asplenium elliottii, Asplenium dregeanum, Dryopteris manniana, Oplismenus hirtellus.*

5.10 Patterns of species occurrence and statistical significance

The finding of this study showed that the global p-value 2.5595e-12<0.5 showed a statistical difference among forest types studied and study periods. This statistical difference was driven by differences environmental factors among which the past anthropogenic disturbance which affect biotic relationships (Trivellone *et al.*, 2017) justified larger number of species occurrence in the secondary forest and Gasumo subjected to the high level of disturbance. *Acacia montigena* as well other lianas were involved in diversity reduction and favoring invasive species such as *Solanum chrysotrichum* mostly in secondary and buffer zone. This support the statement that the higher level of disturbance affect not only the species diversity but also promote the growth of invasive species (Gogoi & Sahoo, 2018). In addition, Adler *et al.* (2018), argued that differences would provide insights on the mechanisms maintaining diversity in natural communities and differences between intra- and interspecific competition may vary among vegetation types, competition may be stronger in light-limited forest communities than in grasslands where species compete for multiple below ground resource (Harpole *et al.*, 2016). Furthermore, microhabitat differentiation inside the forest landscape create a mosaic environments which improve conditions for colonization of different assemblages of plants with different environment requirement such as altitude, soil, vegetation cover commonly known as abiotic filtering (Trivellone *et al.*, 2017).

The intermediate phase, which came after the short rain season and explain the larger number of species in the secondary forest of Cyamudongo. It indicated the growth of pioneer taxa, light demanding species forming a dense undergrowth favored by elevated levels of light availability through forest gap openings as stated by van Breugel (2007) with increase in competitive shrubs and herb understory layers (Markgraf *et al.*, 2020).

The rainfall regime has been mentioned to be a player in shaping the occurrence and composition of secondary and primary forest (Onyekwelu & Yirdaw, 2006) and water availability is a major driver of phonological periodicity in a seasonal tropical rainforest (Gallery, 2016). But, Chen *et al (*2020) concluded that in a same forest, the species diversity is higher in secondary areas than in primary forest thus supporting the small number of species found in the primary forest of Cyamudongo at the final phase of the current study.

5.11 Clusters similarity among pairs of physiognomic communities

The variance analysis based on data of different study periods found that there was no statistical significant difference at the initial phase of the study since the p-value obtained was greater than α (0.479 >0.05). This means that all forest landscapes studied shared a lot of similarities which couldn't allow studied plots to break clearly and split in sub-clusters. This result meet the clustering results presented at fig 77&78 where there were no distinct sub-communities in the clustering patterns for both landscapes areas and their floristic composition. This confirmed the undifferentiated spatial association as defined by Batlle & Van Der Hoek (2018). The similarity should be due to the proximity between sampled areas as large distance may decrease similarity due to variations in gradients and difference in the niche occupation and dispersal limitation (Bao *et al.*, 2018).

A statistical significant difference was found for the intermediate and final phase of the study with a p-value less than α (0.05) of 0.01 and 6.85e-^{12} respectively. This implies significant differences among some pairs of forest landscapes. This finding is similar to the patterns described by the cluster analysis and clusters of close proximity confirmed by Tukey pairwise comparison and results validated as errors followed the normal distribution (fig 89, 90 &91). The clusters group differentiation may depend on gradual variation and interactions of environmental conditions, including temperature, precipitation, light, and soil resulting in increase of the geographic distance between populations (Pritchard & Anderson, 1971).

The adjusted p-value of the intermediate data was found less than α for only the pair of the secondary forest and the primary (0,004<0.05). This show a little change in the community composition of the studied landscapes in comparison to the initial study. This results presented a primary forest of Cyamudongo and equivalent to Gasumo as different from a secondary forest and a buffer zone. In this context, this primary forest is an untouched forest and in the same line, the result meet Kormos *et al.* (2017) exclude indication of human activities where ecological process remain undisturbed. By differentiating the secondary forest from Gasumo, the result emphasized on the disturbance level of the secondary forest where prevailed indicator species are *Macaranga kilimandscharica*, *Syzygium guinense* according to Mlota (2018).

The similarity between the primary forest and the buffer zone indicate a good level of natural regeneration in the buffer zone where the natural vegetation is recovering (Hethcoat *et al.*, 2019). The similarities among plots sampled in different landscape pairs SF-BZ, SF-GS, and GS-BZ reflected homogeneity in plots content and species composition may be due to disturbance such as past agricultural practices, hunting, traditional medicine harvesting, uncontrolled loggings, firewood collections that hindered the development of big trees reduced the canopy favoring the occurrence of similar species and ß-diversity.

At the final phase of the study, Gasumo forest physiognomy distanced from other types given the geographical isolation leading to the presence of 48.54% of vascular plant species found to be confined to Cyamudongo while 7.92% were restricted to Gasumo, thus confirming the statistical differences presented above. Cyamudongo with the studied physiognomic communities separated progressively since 100 years (Fischer & Killmann, 2008) is a an island surrounded by agricultural land. It is assumed that predictable patterns of island variation in species composition may be produced by a variety of factors, such as differences among islands in habitat conditions leading to related differences in species composition if the colonizing species differ from each other in their habitat requirements. In the same way, differences among island in distance to the mainland may cause related differences in species composition if the potential colonizers differ from each other in their dispersal ability (Ronen *et al.*, 2019).

5.12 Effect of level of disturbance and canopy cover on species occurrence

At the initial phase of the study which was extended from the long dry season to the end of short rain season, the general trend showed a positive correlation between the occurrence of species and the canopy cover for all landscapes and the occurrence was higher in disturbed primary, secondary forest than the changed habitat in all landscapes. The disturbance contribute to the canopy opening in the forest has been suggested to be a key player in forest structure as argued by De Lima *et al.*(2008) that openings resulting from tree death known as forest disturbance regime influence the forest structure and regeneration. In the diversity of canopy species in studied sites result a diversity of microhabitats that favor the diversity of understorey species. This is in the line with Nadkarni (1994) that microbitats and substrate types exist within the canopy and contribute to the diversity. During and following the first study period, canopy trees were loosing their leaves creating openings due to the temporal variation in radiation. The correlation between the occurrence of species and the canopy was also previously emphasazed by Michalet *et al.*(2003) that the canopy and understory species had different moisture requirements in studied sites where the correlation between the canopy species and understory assemblages was the highest (Michalet *et al.*, 2003).

The intermediate phase coming after the short rain season, differed with the initial phase where there was only decrease of species occurrence in the primary forest while species occurrence increased with the decrease of the canopy cover in the buffer zone, secondary forest and Gasumo landscapes. At this moment, the canopy cover may have improved in the way to inhibit the growth of the understorey in the primary forest and this was proposed by Yorks & Dabydeen (1999) who hypothesized that with a forest the diversity may continue to increase until the regerating tree canopy layer closes and causes the decline of intolerent species, after which the diversity decreases until tree mortality starts creating canopy openengs. The increase of species occurrence has been also supported by Molina-Venegas et *al.*(2018) who argued that the probability of occurrence of many species increased when the forest canopy cover decreased across landscape scales and this relationship was proposed to detect species degree of forest affiliation as well as to indirectly reflect species response to the spatial configuration of forest fragments.

Moreover in our context, occurrences decreased with the reduction of disturbance in buffer zone and secondary forest while increasing in primary and Gasumo landscapes which is in agreement with Wagner *et al.* (2011) who concluded that the highest tree regeneration densities occurred in low to moderate canopy densities but not under open canopy conditions (Wagner *et al.*, 2011).

On the other hand, the final phase gave similar patterns as the initial in the same research period after 3 years where the species occurrence decreased with the decrease in the canopy cover with exception of the secondary forest and the buffer zone in low canopy cover with high species occurrence in reduced disturbance of Gasumo and primary forest. These results covering the dry season responded to the findings of Joneidi *et al.*(2020), that the occurrence of drought caused the decrease in canopy cover of most studied species. Monitoring the species responses on the variation in precipitation indicated that the effect of drought on the studied species was different and the variation in canopy cover of annual species was more than those of perennial and tree species.

During the study period, the temporal variation of species occurrence was a function of a combined effect of the canopy cover and the disturbance and changes in annual weather patterns in landscapes of broadleaved dominated semi-deciduous or deciduous forests in southwestern part of Rwanda as described by Ndayisaba *et al.*(2017)**.** In these types of forest, the temporal variation in radiation increases their spatial heterogeneity which influence species regeneration and explains the occurrence of juvenile of pioneer species in the forest understorey, argued Hubbell & Foster in Bianchini *et al.*(2001). The spatial arrangement of plants, their crown architecture and leaf area determine the light penetration through the forest canopy can according to Bianchini *et al.*(2001) can help to understand more differences and similarities of species occurrence in the studied forest communities where the greater luminosity of the understorey favored the development of seedlings of some species to the detriment of others, which may have contributed to the forest composition and structural differences among physiognomic communities studied.

5.13 Forest tree communities structure

5.13.1 Distribution of forest age classes

It is well known that within any forest landscape, the relative proportion of the various stages of stand structural and/or stand successional development depends to a large extent on the periodicity, the severity, the spatial and temporal stochasticity of the disturbance event (McCarthy & Weetman, 2006). The description of a forest structure is one of the most important traits which allows deeper knowledge of mechanisms and process responsible for population dynamics. The forest dynamics, structure and development stages are under influences of tree growth, mutual interactions and mortality (Szmyt, 2016). According to Duncan & Stewart (1991), the interpretation of age-class distributions serve to understand the temporal and spatial patterns of tree establishment and stand disturbance history. Age class and trunk diameter at breast height (DBH) were have been amongst the most common measures of tree and plant community structure (Morgenroth *et al.*, 2020).

The pattern of age class distribution in the study period showed different shapes meaning different population structure and composition. The population structure du buffer zone was found to be a typical inverted J-shape distribution pattern which indicated a good seedling recruitment and sapling development potential which is important for future population self-maintenance of the forest reserve as noticed Weldemariam *et al.* (2017). In the past, most of the stands were harvested with even aged cuts and reforestation done implemented using agroforestry species. They are now overcrowded with young trees and these stands are presently in the sapling stage of the growth as according to USDA (n.d.). This population structure depicts that the majority of important tree species showed high population of lower age class resulting in good regeneration (Mishra *et al.*, 2005) and a negative slope which indicate ongoing recruitment or growth suppression where higher proportions are found in smaller size classes than larger ones (Cousins *et al*., 2014). In practice, this distribution pattern displays a smaller proportions of small trees than large trees and almost a constant reduction in proportions of individuals from one age class to the next as pointed out Peters in Gebreselasse (2011). The healthy regeneration of the buffer zone diplaying such pattern has been support by Gebreselasse (2011) explaining the reproductive capacity of individual trees as enough to sustain the forest.

Moreover, the primary forest reversed with the buffer zone and its age class patterns showed a J - shaped pattern of the population as described by Cousins *et al*.(2014) with positive slope limiting the recruitment without excluding an episodic recruitment. This pattern of distribution emerged from either a poor regeneration or poor recruitment of saplings where there is lower proportions of lower diameter classes or age classes and increase in subsequent classes culminating to higher proportions in the highest age class or diameter class as supported by Gebreselasse (2011). As the the primary forest landscape displayed the dominance of canopy trees, the growth of juveniles depends on canopy architecture. It established that within a forest stand, the variation in the vegetation composition, the structure and foliage distribution creates spatial variation in light transmittance in undertorey affecting the growth affecting the growth and morrality of tree seedlings and saplings (Montgomery & Chazdon, 2001). In the case of a' J'-shape distribution, light demanding and early pioneers require large canopy gaps for regeneration as asserted Peters in Gebreselasse (2011). Although, it's always beneficial. The canopy opening by varying levels of disturbance often results in plant destruction and stimulate the growth of dense, herbaceous and semi-woody plants that suppress regeneration (Omeja *et al*., 2004). On the other hand, the reduction in herbaceous competition as a result of shading whereby the presence of nearby shrubs or trees further enhances the probability of woody establishment (Coop & Givnish, 2007).

The 'U'-shape displayed by the secondary and Gasumo forest landscapes is an indicator of disturbance in the forest stands. During his research in Kenya, Gebreselasse (2011) analyzed tree diameters of key species and identified the 'U'shaped pattern oberved on *Olea welwitschii, Croton megalocarpus* and *Celtis africana* point out that the selective loging of medium size trees for charcoal production and pit sawing. In the current study, disturbances due human activities was daily oberved where trees were logged by neighboring communities such as Batwa populations at Cyamudongo and local populations at Gasumo. Some species were evenly observed tageted for their barks such as *Ocotea usambarensis, Parinari excelsa* for medicines and many others for their wood quality, fire wood collection and for agricultural purposes. Montgomery & Chazdon (2001), hypothesized that vegetation dynamics in young stands involve recruitment in sub-canopy gaps below the canopy. Even although, disturbance are known to contribute to the decline of the biodiversity and lead to extinction of species as supported by Alroy (2017) who estimated secondary to be > 18% less rich than primary forests, they foster high diversity by creating canopy openings. Forest fragments and forest disturbed by anthropogenic activities are not significantly less rich than the primary forest as observed in the data set (fig. 104) due to large increase in saplings. The increase in seedlings and saplings followed by the slowdown of the intermediate age of poles and the increase in frequency of mature trees has been supported by van Breugel (2007). The later, argued that in the secondary forest, tree density show highly variable dynamics, the youngest site displays a rapid increase for the first 4 years, followed by a rapid decline in density due to the dynamics of dominant tree species. The density changes varied widely over time; in in the older sites, some plots showing no changes in tree density while others decrease or increase.

5.13.2 Height class distribution

The shade is a function of the photosynthetic activity by which trees supply the carbon to stems to support plant tissues and elevate leaves above competitors and into sunlight. In closed canopy forest, plant compete for light with neighboring plants and the capacity to shade is determined by winners (O'Brien *et al*., 1995). According to Gebreselasse (2011), the population stucture in the tropics has been defined as size-class and diameter distributions of indivuduals and height has been used to estimate the length of time required for species to reach the camopy of the forest (O'Brien *et al*., 1995). The height class distribution in the landscapes forest studied allowed to detect some patterns that allowed to have insights on the structure of the communities. It was observed that the overall height class distributions showed shapes of an inverted 'J'distribution pattern in the three phases of the study which was reflected in different types of communities studied such as the buffer zone, secondary forest, and primary forest and Gasumo forest landscapes. In this kind of distribution, all communities displayed highest relative frequencies in small than in large trees and a progressively decrease in frequency from one class to the next. This finding is in accordance with Liyew *et al.* (2018) who point out that the pattern is exhibited by classes with high relative frequency of individuals in the first and second height classes and with gradual decrease of larger sized trees suggesting adequate seedling reproduction and regeneration. A Similar statement was previously made by Feyera in Gebreselasse (2011) that the pattern is an indicator of healthy regeneration of the forest and species and show a good regeneration and recruitment capacity. According Mensah *et al*. (2020), an inverted-J shaped distribution pattern, is a typical feature of size class distribution in natural forests

However, some particularities were observed among landscapes and study phases. Even though, the relative frequency was low at the initial phase in the lower classes, there has been frequency increase at intermediate phase with almost a same trend for the primary and the secondary forest but a bit far from the buffer zone and Gasumo landscapes. This may be due to the spatial and temporal variability where the break between groups was not clear, thereby making sub-communities not distinct from each other due to an undifferentiated spatial association as defined by Batlle & Van Der Hoek (2018) or the temporal variation in radiation which increases the spatial heterogeneity which influencing species regeneration and occurrence of juvenile of pioneer species in the forest understorey as argued Hubbell & Foster in Bianchini *et al.*(2001). Our finding revealed that the primary forest and Gasumo held higher relative frequency in lower height classes that other forest types for the good reasons that seedlings in shade attained higher height than in open forests and the effect of light on height was significant as asserted by Bekele (2000). In addition, the findings of this study showed that the height did not differ significantly between forest types. But, according to Senf *et al.* (2020), canopy height diversity decreases rapidly, with increasing disturbance rates resulting in a structural homogenization of forests at both the patch and landscape scale and the more homogeneous size distribution and species composition of the second-growth forest canopy and sub canopy layers are associated with increased spatial homogeneity of diffuse light transmittance within the understory, compared to old-growth stands.

5.14 Raunkiar's life form spectra

The phytospectrum of the present study shows variation from the normal biological spectrum of Raunkiaer (1934). According Du Rietz (1931), life forms allow to investigate how plant within changing conditions responded. Life forms associate plants to climate, condition for certain vegetation to survive unfavotrable seasons. The argument that changes in the flora due to human activities never affected the proportions of life forms in its biological spectrum has been examined in the current study.

Based upon the finding of this study, the vegetation of studied areas was found to be dominated by phanerophytes at a high level for both the buffer zones, secondary, primary and Gasumo forest landscapes with a mean percentages of 69.60%, 69.30%, 84.67% and 61.14% followed by geophytes. With addition of epiphytes to phanerophytes increased to 74.3%, 81.6%, 89.5%, and 78.5% respectively. In this study, Phanerophytes showed the maximum divergence from the normal spectrum as given by Raunkier (Smith, 1912) where the spectrum given by the whole flora of the earth estimates Phanerophytes at 46%. Accordingly, the vegetation studied responded to the “phanerophyte-climate » defined in the tropics with mega-nanophanerophytes prevailing in the moister tropical regions as argued Du Rietz (1931). The phanerophyte climate has been reported by other researchers (Hua, 2008; Meher-Homji in Thakur (2015); Cain (1950). In addition, de Meneses Costa e*t al.*(2016) supported our finding and argued that both semi-deciduous and ombrophilous forests were characterized by a strong predominance of Phanerophytes, showing that ecological constrains in both ombrophilous and semideciduous forests do not impose periodical reduction of the plants’ aerial parts. The results of life forms indicated that the primary forest sites owned a higher percentage of Phanerophytes that other physiognomies studied which in agreement with the assertion of Rixen *et al.* (2007) that Raunkiaer life forms that had greater cover in un disturbed than in disturbed sites. The trend of life form spectra were found almost similar among all phases of the study with decreased frequency between the initial and the intermediate phases and became different with the final phase of vegetation sampling. Changes may be due to the biological disturbance which may alter the proportions of life forms as it was stated by Malik *et al.*(2007) that the biological spectrum may be materially changed due to introduction of Therophytes like annual weeds, due to biotic influences like agricultural practices and grazing, deforestation and trampling etc. The comparative accounted of life forms means attributed 8.08%, 3.91%, 2.40%, 5.93% respectively for BZ, SF, PF and GS. This higher mean percentage of Therophytes observed in the buffer zone and Gasumo explained the high level of disturbance in these communities than the primary forest and the secondary forest. The percentage of Therophytes decreased in the buffer zone while increasing at Gasumo in the three phases of vegetation sampling explaining that Gasumo was continuously disturbed than Cyamudongo. The same means revealed a correlation between Therophytes and Geophytes because the seed of a Therophytes survives the unfavorable season in the same subterraneous way as the bud of the geophyte (Du Rietz, 1931). The cluster analysis of life forms allowed to detect similarities among studied landscapes in three phases of vegetation sampling. The the secondary forest (SF3) and Gasumo (GS3) at the final phase were clustered together and closer to the cluster of all buffer zones. This proximity with the buffer zone revealed a canopy opening in the cluster members allowing a natural regeneration due to a disturabance regime with eruption of microphanerophyutes under higher phaneropytes balanced with nanophanerophytes and discarded from the first vegetation survey of the secondary forest (SF1) accumalating higher number of all phanerophytes, epiphytes and geophytes. The change in life-form spectrum due to disturbance has been support in different works. Life-forms were found most useful in characterizing community response to different disturbance types according to McIntyre, (1995). Sheil (2016) concluded that the low levels of disturbance favor slow-growing species with high resilience to competition. In addition, increasing disturbance frequency favors species with more rapid life cycles. Large-scale disturbances favor good colonization abilities. According to Thakur (2015), the therophytes life-form were observed to be favored by disturbance and McIntyre (1995) had previously noticed that higher numbers of geophytes, chamaephytes, phanerophytes are favored in undisturbed habitats which may decrease their vegetative reproduction with soil disturbance while geophytes loose their competitive ability of geophytes in water enriched environment.

Furhermore, there was a similarity between the primary forest (PF1) and Gasumo (GS1) at the initial vegeratation survey and in close proximity with the 2rd survey of Gasumo (GS2) which is clustered with the 3rd phase survey of the primary forest (PF3) as well as with the second phase of the secondary (SF2) and the primary forest (PF2). The two cluster groups holding a high number of higher forms of phanerophytes and higher number of microphanerophytes & nanophanerophytes, juvenmile trees described the forest stands studied as completing the natural regenation from tree seeds.The higher presence of megaphanerophytes and nanophanerophytes indicate a moister tropical rainforest as described by Du Rietz (1931) where higher canopy trees serve are host of a diversity of epiphytes, thus defining a phanerophytic climate. Due to the development of these multiple canopy layers, the structure of the regeneration forest was complex in the forest landscapes related these cluster groups as pedicted by Lichao *et al*., 2008).

5.15 Phytogeographical aspects of the study vegetation

According to Kolahi & Atri (2014), the Chorotype distribution of plants reflects the climate conditions and the flora of sub-Saharan Africa is known to hold a high degree of patterning as asserted Linder (2001). The vegetation of Cyamudongo and the closest area of Nyungwe was found to belong to distinct geographic areas. Nevertheless, their ranges transgress the limits of the major phytochoria and it is convenient to treat them separately. It was also argued that species richness may be more responsive to changing climates than the proportion of range restricted species, so that the areas between the refuges may have a high species richness, but will have a lower proportion of range restricted species, than the refuges (Linder, 2001). The largest phytochoria distribution with the most of plants chorotype of 37.76% and 25.31% was related respectively to the tropical Africa and Guineo-Congolian region. The tropical region of

Africa encompass the total area between the tropics of Cancer and Capricorn and help to define find both ends of most gradients between 24°N to 24°S as argued (Marshall *et al.*, 2021). In this context, 37.76 % of species accounted for tropical Africa are favored by environmental variables between tropics and have a larger area of distribution in Africa that the remaining species; where protected areas are important regions of diversification and persistence as hypothesized by Dagallier *et al.* (2020).

Out of the total number of species recorded, 23.2% were located in Guineo-Congolian region. It was found that among these species some were confined to the phytochoria while others were linking species shared by adjacent or distant phytochoria as observed by White (1979). During his investigation, White established that very few Guineo-Congolian species extend to other phytochoria where 80% were estimated to be Guineo-Congolian. This is in the contrast with the finding of this study, where it was found a high level of ecological and chorological transgression with only 39.02 % found to be restricted to Guineo-Congolian while 30.2%, 42.28% and 5.69% where respectively shared with the Afroriental, Zambesian and both the Madagascan and Usambara-Zululand phytochoria. This show that the flora composition of the study area differ from the Guineo-Congolian by sharing more similarities with the afroriental and the Zambesian regions. The result agreed with the hypothesis of Linder (2001) that species richness may be more responsive to changing climates than the proportion of range restricted species, so that the areas between the refuges may have a high species richness, but will have a lower proportion of range restricted species, than the refuges and to the conclusion that the species richness is much lower in the north than in the south.

The flora diversity of Cyamudongo and Gasumo falls also in the Sudanian with 10% of the total record but with species linkage to other phytochoria which extends from Senegal to south Soudan and pass in South into the Guineo-Congolian according to White in Brenan (1978b). These proportions are higher than the ecological and chorological transgressors of the Guineo-Congolian to the Sudanian estimated at 3% by White (979).

The finding of this study confirmed the similarity between the flora diversity of the study area and the Sudanian phytochorion. These similarities between different phytoregions; have been suggested by Shumba *et al.* (2010) that some flora may be found in the African dry forests and woodland of the Sudanian phytoregion. For instance, the results showed that the flora extended to the Sudanian is predominantly made Phanerophytes and Therophytes and lack epiphytes as proven by Abutaha *et al.* (2020) where they found that the flora diversity of the studied area in Sudanian was dominated by Therophytes and Phanerophytes of large proportions of tropical shrubs and trees.

Considered as mountain forests and parts of Afro-montane forest (RDB, 2017; Fischer & Killmann, 2008), Cyamudongo fragment and the studied area reflected similarities with the Est Africa mountains and the Africa tropical mountains for respectively 2.49% and 0.41 % of the total flora identified and species linkages were found to be extended on Islands. Since, Cyamudongo has been isolated from 100 years, the geographical isolation and variance or long-distance dispersal may explain the distribution of this flora in different phytochoria with different ecological and chorological transgressions as in some studies (Kropf *et al.*, 2006; Bartish *et al.*, 2011).

Furthermore, 10 plant species identified in the study are known to be restricted in Nyungwe, therefore endemic for Nyungwe. This level of endemicity is high and should increase with research efforts if compared to available data on the whole massive according to Fischer & Killmann (2008) and Pintea *et al.* (2011) who estimated the number of local endemic around 47 endemics species and about 280 Albertine Rift endemics.

CHAPTER 6. CONCLUSION AND RECOMMENDATIONS

6.1 Vegetation cover changes

Nyungwe has been gazetted as forest reserve in 1933. Since this time its surface reduced around 20% due to logging and conversion into agricultural landscape (Fischer & Killmann, 2008). The forest has been fragmented and Cyamudongo separated since almost a 100 years ago but Nyungwe remains the largest blocks of montane rainforest remaining in Africa with a surface area of 1000 km^2 (MUsabwamana, 2019). Human population pressure increased around NNP and Cyamudongo and continued to destroy the forests isolating populations into fragments. Following continuous natural forest encroachment around Nyungwe NP, tree plantations were established in 1984 at the edge to stabilize the park boundary and create wood stock for the timber industry (Arakwiye *et al*., 2021). There was a need to understand how the flora diversity responded to human imposed challenges and forest restoration initiatives. This study explored the influence of human activities on the flora diversity and vegetation of Cyamudongo rainforest fragment, the adjacent forest plots and the western Nyungwe main block. Braun Blanquet methods for the vegetation survey. Species life-forms were evaluated and tree species dbh and height have been measured. Data were subjected to statistical analyses using different softwares such as PAST, R 3.5.2, and SPSS. The mapping was done using Arc GIS and the Multi-Spectral Remote Sensing used to find NDVI for the vegetation classification. Early results suggested a change in vegetation cover and its classification in the study areas and during the study period where areas of sparse changed to moderate vegetation and moderate to higher dense vegetation which improved better at the end of the research than the beginning and the lowest vegetation cover was mostly found in surrounding areas of Cyamudongo and Gasumo suggesting a high level of disturbance. NDVI trends showed that there has been fluctuations in vegetation classifications of the studied area. Changes in NDVI values and their corresponding surface areas depend heavily on changes occurring at the level of the ecosystem causing fluctuations on vegetation types, quantity and quality as suggested by Huang *et al*. (2019). Causes of changes in the NDVI values, may include Cyamudongo project involvement in tree planting in surroundings of Cyamudongo which may have influenced the NDVI values as it was supported by Li *et al*. (2011). The impact of the project on weather with increasing evapotranspiration resulted in increase of precipitations and relative humidity and rainfall duration allowing the vegetation growth and NDVI values improvement for more dense vegetation. At the end of the study, the results showed that a higher dense vegetation dominated other vegetation classifications than it has been the period before where the land cover tend to increase and stabilize which may have been due to low deforestation rate, strengthened protection measures and tree planting for communities surrounding Cyamudongo.

6.2 Floristic composition and species diversity

The vegetation surveys revealed that 494 vascular plant species from 106 families were harbored in the study area and distributed differently among forest landscapes and study phases. Although, 43.54% were common to Cyamudongo and Gasumo landscapes while 48.54 % of species diversity were hold only by Cyamudongo and 7.92% confined to Gasumo. On the list of recorded species, *Illigera pentaphylla* Welw, *Hetaeria heterosepala* (Rchb. f.), *Begonia ampla* Hook. F., *Dorstenia psilurus* Welw, *Englerophytum natalense* (Sond.) T. *Penn*, *Aidia micrantha* (K. Schum.) F. White*, Psychotria avakubiensis* De Wild., *Psychotria ceratoloba* (K. Schum.) O. Lachenaud, *Psychotria ealaensis* De Wild, *Psychotria nigropunctata* Hiern, *Psychotria punctata* Vatke, *Leptoderris burundiensis* Bamps & Champl., 12 in total were found new records for Rwanda while several others suspected require detailed research for identification. This shows how the flora diversity of Cyamudongo is of special interest and extremely important for discoveries.

Among landscapes, the primary forest harbored the lowest occurrence of spermatophytes and the secondary forest has been the highest for both spermatophytes and Pteridophytes where 75 % of dominant families which are among the top 12 such as Rubiaceae, Aspleniaceae, Asteraceae, Orchidaceae, Apocynaceae, Fabaceae, Urticaceae, Moraceae, Acanthaceae, Euphorbiaceae, Sapindaceae, Meliaceae are reported to be the richest in Africa tropical forests according to Sosef *et al*.(2017) and in similarity of family composition with Kahuzi-Biega National Park, within the Albertine Rift with the dominance over different life forms by families of Rubiaceae and Fabaceae as witnessed by Cirimwami *et al*.(2019). 153 species were common to primary, secondary and the buffer zone of Cyamudongo and 115 common to Cyamudongo and Gasumo studied landscapes. 27 species were restricted to Gasumo and 62 present exclusively in Cyamudongo which explained differences in species composition between Cyamudongo and Gasumo then this come to support the argument of the existence of refugial area in mountain ridges around Lake Kivu and of unicity of the flora and vegetation of Cyamudongo (Fischer & Killmann, 2008). The overall results showed that the forest landscapes studied have been found to be favorable for the growth of pteridophytes and mostly epiphytes. This occurrence a side to angiosperms depend to the increased precipitations that accompanied the angiosperm diversification in tropical rain forests which favored the climate regime due to their evapotranspiration as pointed out Branch (2014). Furthermore, the disturbance was found to shape the species diversity and a route for the occurrence of invasive species such as *Solanum chrysotrichum* observed occurring mostly in the buffer zone and the secondary forest. For instance, the α-diversity was found higher in more disturbed landscapes than in primary forest as a result gaps openings which favor new species and increased species diversity and this is consistent with the finding of this study where the species richness was found higher in buffer zone, secondary and Gasumo forest than in primary forest landscape at the initial phase due to extensive and frequent human disturbance as proposed by Williams in Van Andel (2001). This corrabote with observations obtained during the survey with regular tree logging, fuel wood and non-timber products collection by surrounding communities both at Cyamudongo and Gasumo. The effect of the seasonal variation on species richness drived plant phenological response where normally, the mean annual rainfall is lower with dry season months and characterized by greater evaporative potential than precipitation. In this contex, it occurred a change in species richness from the initial to the intermediate phase where there has been increase and heterogeneity in species number composition in the buffer zone, secondary forest and Gasumo landscapes while the α-diversity decreased in the primary forest in the period of short rain season 2019. The effect of the dry season has been observed at the final phase of the study and was referred to the reduction of humidity during the dry season with a general decrease of α-diversity in primary forest and buffer zones dominated by the secondary forest and Gasumo. The variation in α diversity within landscapes mostly in buffer zones, secondary forest and Gasumo may be associated to environmental heterogeneity and associated variation in microclimatic conditions, and accounting for the higher species richness and diversity with exclusive species to these environments. In addition to α-diversity, the global beta-diversity of the initial phase of the study was higher than ones of the following study phases and a high global beta-diversity impact community visualization using ordination methods as communities are overlapping mainly due to anthropogenic impacts where localized species are lost and invader are established causing increase of ß-diversity. Findings showed that ß-diversity of the initial phase of the study was higher in all landscapes and decreased with succeeding phases with very little difference meaning that a high level of dissimilarities within and between assemblages of landscapes under study and individual localities differed one another. Higher and changing of beta diversity in the buffer zone, primary and secondary forest as well Gasumo may be referred to different environmental conditions, seasonal variations and disturbances as for α-diversity. The heterogeneity nature was also confirmed by the evenness, Simpson and Shannon index trend lines with distinct patterns for forest landscapes under study for different periods of the study. Even though, index values were high at all research phases; the buffer zone, the secondary forest and the second phase of the primary forest and Gasumo landscapes showed a high level heterogeneity while a good level of homogeneity appeared at the initial and final phases of the primary and Gasumo landscapes due distribution of species relative abundances and the primary forest and Gasumo landscapes were found more even than the buffer zone and the secondary forest landscapes of Cyamudongo. Differences in index trend lines were observed from one study phase to the other and variations may have depended on soil moisture and the spatial variation of the abundance of dominant species, ecological processes such as competition, predation, succession and the seasonal variation of weather which alter the proportional diversity as well as dynamic nature of different habitats experiencing disturbance that increase habitat heterogeneity, propagule arrival and colonization and plant community response to disturbance would vary depending habitat stability as pointed out from literature. As proven by alpha and beta diversities; the heterogeneity in species composition has been influenced by the disturbance and it is in conformity with patterns of trend lines of all diversity indices analyzed.

6.3 Landscape communities internal structure

The pattern of the internal structure of communities, similarities and differences as well as species environment relationship were detected by the Principal component analysis of data as recommended by Chahouki (2012). In this context, the first principal component attributed the greatest variation in the community composition to the secondary forest landscape for the first and the intermediate vegetation surveys and to the primary forest at the final survey. Landscapes were almost part of the secondary and at to some extend included in diagram of the secondary forest and sharing a lot of similarities. Only the primary forest and the buffer zone distanced slightly from the secondary forest respectively for the initial and intermediate phases of the study with changes in species composition. This pattern may result from a combination of anthropogenic and natural disturbances. The primary forest improved better at the final phase with the highest variation in species composition as arranged along with the first principal component and others landscapes remained with the highest similarities. The internal structure of community landscapes defined a spatial heterogeneity as described by Gibson (2002) with changes in species composition from a the study phase to another.

6.4 Factors of Landscape communities internal structure

The CA identified drivers of community structuring. The most important factor is the disturbance which allowed the occurrence of closely related species due to habitat filtering defined by Li *et al.* (2018). All landscapes shared big similarity with secondary forest, except portions of primary forest and Gasumo. The level of similarity among landscapes has been confirmed the statistical analysis with MANOVA and ANOVA. The occurrences of common species may have resulted from habitat filtering and reduction in canopy and consequently the growing of many species whose characteristics of taking advantages leading to the increase in beta diversities in the areas. Additionally, the decrease of the overlap has been facilitated by dominant plant mostly light competitors. In this sense, *Acalypha psilostachya* and *Acalypha neptunica* are associated positively to secondary, the buffer zone and the secondary forest with the longest amplitude extended on the first principal components. Lianas were involved in the structure and composition of communities. *Acacia montigena, Urera hypselodendron, Dalbergia lactea* mostly growth inbitors and killers of canopy trees shaped the community structure and gap dynamics with a negative impact and a decrease of the general diversity in the secondary forest, primary forest and Gasumo landscapes mostly. Multiple environmental factors shape local species assemblages by progressively filtering species from the regional species pool to local communities (de Bello *et al.*, 2013). Even though, the weather variables were not used for the assessment, different periods of vegetation surveys imply different weather conditions (moisture, temperature, light, atmospheric changes including ultra-violet light, and disturbance regimes) have led to different results with different structure of communities.

Altitude as well as the combined effect of the canopy cover and heavy lianas such as *Acacia montigena* were found to be engine of community structure as it has been found respectively in lower altitude with no or low disturbance where species belong to a same community with similarity in species composition and clouded in the center and at Gasumo studied area.

6.5 Landscape forest trees structure

According to Gebreselasse (2011), the population stucture in the tropics has been defined as size-class and diameter distributions of indivudual trees. The description of a forest structure is one of the most important traits which allows deeper knowledge of mechanisms and process responsible for population dynamics. The forest dynamics, structure and development stages are under influences of tree growth, mutual interactions and mortality as pointed out Szmyt (2016).

The pattern of dbh class distribution showed an inverted J-shape, a J - shaped pattern and 'U' shape patterns respectively for the buffer zone, the primary forest and both the secondary and Gasumo forest landscapes corresponding to different population structure and composition. A typical inverted J-shape distribution pattern indicated a good seedling recruitment and sapling development potential which is important for future population self-maintenance of the forest reserve as noticed Weldemariam *et al*. (2017). In practice, this distribution pattern displays a smaller proportions of small trees than large trees and almost a constant reduction in proportions of individuals from one age class to the next as pointed out Peters in Gebreselasse (2011). A 'J 'shaped pattern for the primary forest is a reversed of the buffer zone with positive slope limiting the recruitment without excluding an episodic recruitment. This pattern of distribution emerged from either a poor regeneration or poor recruitment of saplings where there is lower proportions of lower diameter classes or age classes and increase in subsequent classes culminating to higher proportions in the highest diameter class as supported by Gebreselasse (2011). The primary forest landscape displayed the dominance of canopy trees where the growth of juveniles depends on canopy architecture. Moreover 'U'-shape displayed by the secondary and Gasumo forest landscapes is an indicator of disturbance in the forest stands. The disturbances due human activities was daily oberved where trees were logged by neighboring communities such as Batwa populations at Cyamudongo and local populations at Gasumo. Some species were evenly observed targeted for their barks such as *Ocotea usambarensis, Parinari excelsa* for medicines and many others for their wood quality, fire wood collection and for agricultural purposes.

height has been used to estimate the length of time required for species to reach the camopy of the forest (O'Brien *et al*., 1995). On the other hand, the overall height class distributions showed shapes of an inverted 'J'distribution pattern in the three phases of the study reflected in different types of communities studied such as the buffer zone, secondary forest, and primary forest and Gasumo forest landscapes where all communities displayed highest relative frequencies in small than in large trees and a progressively decrease in frequency from one class to the next suggesting adequate seedling reproduction and regeneration. This agreed with Feyera in Gebreselasse (2011) statement that the pattern is an indicator of healthy regeneration of the forest and species and show a good regeneration and recruitment capacity.

6.6 Community Clusters

In clustering analysis with Manhattan similarity, the break between groups was not clear, thereby making sub-communities not distinct from each other from an undifferentiated spatial association mostly for the initial vegetation survey and Distinct clusters were better obtained at the intermediate phases that others. Trends observed were different among study phases may be due to the disturbance and the effect seasonality leading changes in clusters patterns. Clusters showed more heterogeneity where members formed from different forest landscapes due to similar floristic composition under the control of different environmental factors and indicators species in the cluster presented the highest amplitude.

Patterns of clusters showed a close similarity between the Gasumo landscape and the primary forest of Cyamudongo and characterized by natural forest dynamics in tree composition with occurrence of dead wood and a natural regeneration process as stated by FAO in Kormos *et al.* (2017) andiIndicator species have been high canopy tree species such *Elaeodendron buchananii, Magnistipula butayei, Trilepisium madagascariense, Entandrophragma excelsum, Chrysophyllum gorungosanum.* The close proximity of the homogenous or mixed buffer zone with similarities to primary forest landscape forest implies a semi-natural forest where the natural regeneration is being achieved. The cluster members of the floristic composition of forest landscapes and corresponding life forms depended mostly on their landscape components where indicator species of clusters close to the secondary forest are characterized by the presence Geophytes and Chamaephytes, able to propagate vegetatively and resist disturbances.

The spatial arrangement of plants, their crown architecture and leaf area determine the light penetration through the forest canopy proposed by Bianchini *et al.*(2001) can allow to understand more the clustering of physiognomic communities together with differences and similarities of in species occurrence where the greater luminosity of the understorey favored the development of seedlings of some species to the detriment of others, contributing to the forest composition and structural differences among physiognomic communities. Differences between and among forest types studied and study periods were driven by differences in environmental factors among which the past anthropogenic disturbance that affected the biotic relationship justifying larger number of species occurrence in the secondary forest and Gasumo subjected to the high level of disturbance with key indicator species.

6.7 Raunkiar's life form spectra

Life forms allow to investigate how plant respond within a changing environment (Du Rietz, 1931). The overall finding of the study showed that by phanerophytes dominated at a high level followed by geophytes for all the forest landscapes. Phanerophytes showed the maximum divergence from the normal spectrum as given by Raunkier in Smith (1912) where in the spectrum given by the whole flora of the earth Phanerophytes are estimated at 46%. Accordingly, the vegetation studied responded to the "phanerophyte-climate » defined in the tropics with mega-nanophanerophytes prevailing in the moister tropical regions as argued Du Rietz (1931). The argument that changes in the flora due to human activities never affected the proportions of life forms in its biological spectrum has been examined in the current study instead, changes due to disturbance are reflected in decrease or increase of lower life forms.

The trend of life form spectra was found almost similar among all phases of the study with decreased frequency between the initial and the intermediate phases and became different with the final phase of vegetation sampling. Changes may be due to the biological disturbance which may alter the proportions of life forms as it was stated by Malik *et al.*(2007) that the biological spectrum may be materially changed due to introduction of Therophytes like annual weeds, due to biotic influences like agricultural practices and grazing, deforestation and trampling etc.). The cluster analysis of life forms hilighlighted similarities between the primary forest, Gasumo and secondary forest and differences between tem and the buffer zone.

6.8 Phytogeographical aspects of the study vegetation

The flora diversity of Cyamudongo and the study area of Gasumo was found to reflect different climate conditions. This flora was found to belong to different phytogeographical districts with ranges transgression of the limits of the major phytochoria. The largest phytochoria distribution with the most of plants chorotype was related to the tropical Africa encompassing encompass the total area between the tropics of Cancer and Capricorn and help to define find both ends of most gradients between 24°N to 24°S and the Guineo-Congolian region. The high proportion of species accounted for tropical Africa is favored by environmental variables between tropics and the remaining protected areas considered as important regions of diversification and persistence (Dagallier et al., 2020). More other species were found to be confined to the Guineo-Congolian region while others behaved as linking species shared by adjacent or distant phytochoria as observed by White (1979) corresponding to ecological and chorological transgressors among phytochoria. Not only moisture conditions were the factor of the phytogeographical distribution, several species were found distributed in the Sudanian phytoregion or having a distribution on islands. This flora extended to the Sudanian is predominantly made Phanerophytes and Therophytes and lack epiphytes as proven by Abutaha *et al.* (2020). In fact, Cyamudongo was isolated for long time; the geographical isolation and vicariance or long-distance dispersal may explain the distribution of this flora in different phytochoria with different ecological and chorological transgressions as in some studies (Kropf *et al.*, 2006; Bartish *et al.*, 2011). Furthermore, the area was found with a high level of endemicity which should increase with additional research efforts.

To summarize, results on diversity indices, the PCA, CA and the Cluster analysis, the all statistical analyses (MANOVA, ANOVA), life forms unanimously showed that the anthropogenic disturbance influenced, the vegetation cover, the floristic composition, the species diversity, the forest landscapes community structure, the life form spectrum and the phytoclimate of Cyamudongo and Gasumo forest landscapes. The overall findings of the study showed that cluster groups were heterogeneous and overlapping and species associations not clearly defined due to the high level of similarities in species composition among forest landscapes and vegetation surveys. The species diversity was found high in secondary forest and Gasumo landscape forest and low in the primary forest and the buffer zone of Cyamudongo and the disturbance with gaps openings was found to be associated to the species diversity with a seasonal variation. The patterns of dbh for the buffer zone and of the size classes of all landscapes with an inverted 'J' indicated a healthy regeneration in the forest landscapes and tree species explained a good regeneration and recruitment capacity. Different shapes in the pattern of dbh with respectively an inverted 'J', 'J 'and 'U' for the buffer zone, primary and together the secondary and Gasumo forest landscapes indicated differences in the landscapes health and degree of regeneration and recruitment capacity.

In the period of Cyamudongo project implementation, important achievements include the increase of forest biomass and therefore the photosynthetic capacity and the evapotranspiration potential that influence the rainfall regime; the regulation of weather conditions and then species diversity; supporting local communities and limiting human activities; raising awareness on conservation and protection of biodiversity and improving of living conditions of neighboring populations by providing paid employment and so to restore to the Cyamudongo forest ecosystem functions.

Cyamudongo forest remain vulnerable as surrounded by local communities with a high population pressure relying on forest resources for its survival. Cyamudongo harbors a high level of endemism and is a small hotspot for biodiversity conservation. It is therefore

recommended to strengthen conservation and protection measures and continue the support of local communities. Further researches may help to have a deeper knowledge and include:
The assessment of the conservation and the IUCN status of key species of Nyungwe National Park that will serve as baseline to guide policy making for the conservation of biodiversity. A long term vegetation monitoring of Cyamudongo may help understanding the impact of climate change and shift in species diversity composition and distribution. To investigate and confirm the existence of species refuge and to understand patterns of ecological and chorological transgression of the flora diversity of Cyamudongo in different phytochoria. An assessment of the relationship between weather conditions, soil properties; the geomorphology and the current and fossil flora diversity will help to understand the current and past vegetation history of the flora diversity of Cyamudongo. Furthermore, for scientific research reasons, it is imperative to continue and support the botanical exploration of Cyamudongo and the southwestern part of Nyungwe

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Education

Since 08/2017	PhD candidate in Biology at the University of Koblenz-Landau, Germany
09/2010-09/2012	MSc in Biology of Organisms and Ecology, Botany option at University of Liege, Belgium
09/2001-2003	2nd University cycle, in Biology, Botany option at the National University of Rwanda (B.Sc. in Botany)
09/1989-1992	First University cycle in at the National University of Rwanda (Baccalaureate)
9/1981-7/1987	Pedagical studies at Ecole des Scies Byimana, Rwanda

Work experience

Since 06/2013	Lecturer and Coordinator of Botany garden at INES-Ruhengweri& Head of Biotechnology Department 2015-2019 in the Faculty of Applied Sciences
05/2005-08/2009	Botany Research Assistant at Karisoke, Dian Fossey Gorilla Fund International (DFGFI)
09/1992-04/2005	Teachers in Secondary schools at Groupe Scolaire Butare, Ecole Secondaire Nyamagabe and Ecole des Sciences de Musanze
9/1987-09/1989	Teacher at College Gitwe, Gitarama

Training and Conferences

01/2020	Training for the IUCN red list for evaluation of plants at Meise Botany Garden, Belgium
11/2019	Training on integrated groundwater resources management, Biodiversity assessments and maping in Rwanda at University of Rwanda
02-05/05 2012	Oceanography and aqwuariology at Wimereux Marine Biology, France
10-13/04/2012	Animal Behavior: Case of low land gorillas at Zoo Cologne, Germany
27/08-03/07, 2010	Plant Biogeography and Nature conservation, Alsace & Vosges, France
07-15/05, 2010	Phylogeny and ecology of macaronesian flora at Tenerife (Archipelago of Canaries islands
04/2010	A flora survey and the dynamic of rodents in the park of Cevennes, France

Publications

Nsanzurwimo, A., & Nikuze, F. (2021). Evaluation of different type containers used in micropropagation of Irish potato varieties. INES Scientific Journal, 1(1), 33–42. https://doi.org/10.32677/ISJ.2021.v01.i01.004

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Additional skills

Computer skills	Excellent proficiency in different computer applications packages such as MS Word, M S Excel, Powewrpoint and other statistical softwares including SPSS, PAST, MVSP, Statistica, R and Arc GIS.
Languages	English (Very good), French (Excellent).

DECLARATION

I declare that this dissertation is my independent original work, its parts of in whole own has never been presented in any other University and all the assistance received in preparation of this thesis and sources have been duly acknowledged.

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