Cape Peninsula University of Technology

Vegetation Patterns in Tropical Forests of the Rumpi Hills and Kimbi-Fungom National Park, Cameroon, West-Central Africa

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DECLARATION

I, Sainge Nsanyi Moses, student number 214055434, of Cape Peninsula University of Technology, hereby declare that this study for a Doctoral Degree (Plant Systematics and Ecology) in the Department of Environmental and Occupational Studies, Faculty of Applied Sciences, is wholly my research work. Supporting documents from other authors used in this work have been referenced and acknowledged. This piece of document has not been submitted to any academic institution for assessment. The Cape Peninsula University of Technology, Cape Town in the Republic of South Africa is the only institution with the mandate to assess this work for the award of PhD.

Signature …………………………….. Date: 09/10/2017…………………..

ABSTRACT

Western Cameroon is thought to hold rich biodiversity and diverse vegetation types, and contains two important forest reserves: Rumpi Hills Forest Reserve (RHFR), which is lowland to montane forest located in southwestern Cameroon and Kimbi Fungom National Park (KFNP), which is a semi-deciduous and savanna forest located in northwestern Cameroon. These forest blocks form part of the continental Cameroon Mountains. Thus far, few or limited studies have been undertaken at these two sites to characterise their floristic composition, vegetation patterns, biomass, and carbon stock. Hence, the vegetation of RHFR and KFNP were inventoried from February to November 2015 in detail with the view of describing and understanding the biodiversity and vegetation patterns vis-à-vis elevation gradient. This will enable us to answer the main research questions: How does elevation and vegetation patterns influence species composition, diversity, biomass and carbon in selected wet and dry tropical forests of the Congo Basin? Are plant species equitably distributed among life forms and elevations gradient? What are the extent of land cover changes in RHFR and the KFNP? The objectives of this study were: to characterise vegetation patterns, understand how elevation influences species distributions and diversity, and evaluate biomass and carbon stock per hectare. Furthermore, the study intended to assess the vegetation cover changes over the last few decades in RHFR and KFNP in western Cameroon.

RHFR and KFNP were chosen as representative forests because limited ecological studies have been carried out on these forests, and each represented a tropical wet or dry forest, respectively. The floristic composition and vegetation patterns of the reserves were studied in 25 1-ha plots in the RHFR and 17 1-ha plots in the KFNP spread along elevation gradient and different vegetation types. In each plot, the dbh of trees and lianas of diameter at breast height $\geq$10 cm were measured, and dbh of shrubs <10 cm were measured in nested plots of 10 m x 10 m. Remote sensing data (Landsat images) was downloaded from the Global Land Cover Facility (GLCF) and United States Geological Survey (USGS) websites to assess forest cover changes. Forest cover changes over time were compared for both sites. Satellite images from Rumpi Hills (2000 and 2015) and Kimbi Fungom forest (1979 and 2015) were used to compare past and present vegetation (forest cover changes over time). Phytosociological parameters such as basal area, relative density, relative dominance, and relative frequency were used to described forest structure and composition. The statistical program “PAST” version 2.17 was used to calculate species diversity and richness. Allometric equations were used to evaluate above ground biomass and carbon stock.

In all, 16,761 trees, shrubs and lianas with dbh ≥1 cm, representing 71 families, 279 genera, and 617 morphospecies were sampled in the RHFR. Floristic composition of trees (dbh ≥10 cm) ranged from 94-132 species with a mean of 117.5±14.8 species ha^{-1} in lowland forest (50-200 m); to 36-41 species with a mean of 38.5±3.5 species ha^{-1} in montane cloud forest (1600-1778 m) near the summit of Mount Rata were recorded. Two-way Indicator Species Analysis (TWINSPAN) classified the 25 plots into six vegetation types: lowland evergreen rainforest, lowland evergreen rainforest on basalt rocks, mid-elevation evergreen forest, submontane forest, transitional submontane forest, and montane cloud forest. Detrended correspondence analysis (DCA) of data demonstrated the importance of elevation in shaping vegetation patterns. A total above ground biomass of 9993 t with a mean of 400±100 t ha^{-1} and carbon 4997 t, mean of 200±50 t ha^{-1} were recorded in the RHFR. A negative relationship between carbon and elevation ($r^2 = 6.18$, $P < 0.05$) was detected, whereas a weak positive relationship between species diversity and carbon ($r^2 = 39.13$, $P < 0.005$) were recorded in the RHFR. Based on elevation gradient, we identified four forest types (lowland, mid-elevation, submontane and the montane cloud forest). The density of trees with dhb ≥ 10 cm decreased with higher elevation (50-1778 m asl). A strong significant negative relationship was noticed between species richness and elevation ($r^2 = 75.6\%$, $p < 0.05$) across the 25 ha plot in the RHFR. Based on the satellite images, land cover and land use in the Rumpi Hills Forest Reserve for the years 2000 and 2015 showed no significant changes for the different vegetation types.

In the Kimbi Fungom National Park, a total of 5551 trees, shrubs and lianas of dbh ≥1 cm belonging to 46 families, 121 genera, and 201 morphospecies were recorded. Multivariate analysis (TWINSPAN) revealed five vegetation types: primary semi-deciduous forest, secondary forest, mixed vegetation, gallery forest, and woody and grassland savanna. We found an average of 269.8 tree stems ha^{-1} (range 157-404 tree stems ha^{-1}) and an average of 43.1 species ha^{-1} (range 27-65 species ha^{-1}) at dbh ≥ 10 cm. The five vegetation types had an average above-ground biomass of 194.6 t ha^{-1} ranging from 60.7-489.1 t ha^{-1}, and carbon: 97.3 tC ha^{-1} (30.4-244.6 tC ha^{-1}) in the 17 ha for trees with dbh ≥10 cm. A regression analysis relating above-ground biomass to number of species per hectare across the five vegetation types yielded a significant positive relationship ($r^2 = 0.712$, $P = 0.05$). We also noted a weak positive association between elevation and above-ground biomass across vegetation types. In the Kimbi Fungom National Park, the extent of forest cover change was significant in parts of the forest when satellite data of 1979 and 2015 were compared. Extents of forest cover changes were remarkable in the west around Gayama and Munkep, bringing the size from 978.38 km^2 in 1979 to 972.72 km^2 in 2015.

These results follows the normal pattern that the wet and dry forest are composed of different vegetation types, and that these vegetation types show impressive variation in terms of structure, species composition, diversity, biomass, carbon, and spatial distribution. It also shows that the RHFR and KFNP are potential sites for the study of climate change and (Reducing Emissions from Deforestation and forest Degradation plus Conservation, sustainable forest management and enhancement of forest carbon stock) REDD+ mechanism. Furthermore, the fine-scale inventory data of species, biomass, and carbon obtained in this study could be useful in developing predictive models for efficient management of tropical rain and dry forests.

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To my wife, Benedicta Jailughe Sainge, I say thank you for your words of encouragement, patience, hope and faith during this study period even when times were hard you still stood by me to propel me to higher heights. To all my lovely kids: Elizabeth, Thelma, Morgan, Carlson, and Vivian, I thank you all for your tolerance, hope and faith. To my lovely mother, Regina Nzofene Nsanyi, and father Samuel Nsanyi, I say thank you for being there when I needed your advice and words of encouragement. To Madame Catherine Metuge and Elizabeth Wotany for their encouragement, assistance, and advice. My brothers Nsanyi Joseph, and Nsanyi Paul for their words of encouragement. My sincere appreciation also goes to Pa Paul Tumenta, Elizabeth Tumenta and Rev. Simon Ngalle Njie for their endless prayers and encouragement towards the completion of this thesis.

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Above all, I thank the almighty God for giving me the strength, courage, knowledge, and showing me the way to carry out this work.

Finally, I hope that this piece of work will add value to existing and future studies on the biodiversity, ecology, above-ground biomass, carbon stock and the payment for environmental services to Cameroon and the Congo Basin countries.
Thanks, Merci, Miebucho, SA

DEDICATION

This piece of work is dedicated to my wife Benedicta Jailughe Sainge, my kids: Elizabeth, Thelma, Morgan and Carlson for their patience, courage, love, hope and faith exhibited during my period of study.

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ABBREVIATIONS AND ACRONYMS

AGB	Above Ground Biomass
ANOVA	Analysis of Variances
APG	Angiosperm Phylogeny Group
BA	Basal Area
C	Carbon
CBD	Convention of Biological Diversity
CBFP	Congo Basin Forest Partnership
CCA	Canonical Correspondence Analysis
CDC	Cameroon Development Cooperation
CDM	Clean Development Mechanism
CIFOR	Center for International Forestry Research
cm	Centimeter
CO_2	Carbon dioxide
COMIFAC	Central African Forest Commission
COP	Conference of Parties
CVL	Cameroon Volcanic Line
DAK	Digital Accessible Knowledge
dbh	Diameter at Breast Height
DCA	Detrended Correspondence Analysis
DEM	Digital Elevation Model
E	Pielous evenness
Elev. (m)	Elevation
ENVI	Environment for Visualizing Images
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
FD	Flat Dry forest
GESP	Global Environmental Sustainability Programme
GF	Gallery forest

GLCF	Global Land Cover Facility
GMTED	Global Multi-resolution Terrain Elevation Data
GOFC-GOLD	Global Observation of Forest Cover and Land Dynamics
GPFLR	Global Partnership on Forest Landscape Restoration
$GtCyr^{-1}$	Gegatonnes of carbon per year
G/WS	Grassland/Woody savanna
H’	Shannon-Weiner index of diversity
ha	Hectare
ITTO	International Timber Trade Organization
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
KFNP	Kimbi Fungom National Park
km^2	Square kilometer
L	Lake
Lidar	Light Detention and Ranging laser
ln	Natural logarithm
LULUCF	Land-Use, Land-Use Change and Forestry
m	Meter
MEA	Millennium Ecosystem Assessment
MINEF	Ministry of the Environment and Forestry
MINFOF	Ministry of Forestry and Wildlife
ms	Microsoft
MSS	Multiple Spectral Scanner
Mt	Mountain
MV	Mixed Vegetation
NBSAP	National Biodiversity Strategy and Action Plan
S(obs)	Observed Number of Species
PAST	Paleontological Statistics Software package for education and data analysis
PC-ORD	DOS Program that performs Multivariate Analysis of Ecological Data
Pg/yr	Picogram per year
PL	Plateau
PLC	Public Limited Company
PRSP	Poverty Reduction Strategy Paper
PSF	Primary Semi-deciduous Forest
PVC	Polyvinyl Chloride
QGIS	Quantum Geographic Information System
REDD	Reducing Emissions from Deforestation and forest Degradation
REDD+	Reducing Emissions from Deforestation and forest Degradation plus Conservation, sustainable forest management and enhancement of forest carbon stock
Radar	Radio Detention and Ranging
RHFR	Rumpi Hills Forest Reserve

RSG	Rufford Small Grant Foundation
S	Number of species
SAR	Synthetic Aperture Radar
SD	Stem Density
SF	Secondary Forest
SL	Slope
SW	Swamps
t	Tonnes
TD	Tree Density
TroPEG	Tropical Plant Exploration Group
TWINSPAN	Two-way Indicator Species Analysis
UN	United Nations
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USGS	United States Geological Survey
Vegtype	Vegetation Types
WD	Wood Density
WRI	World Resource Institute
YA	National herbarium of Cameroon

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CHAPTER ONE

1. Introduction

The issues of biological diversity, climate change and agricultural expansion in tropical forest are concomitant and complex, and for decades have inspired many international conventions and agreements (COP03, 1997; COP06, 2002; COP09, 2008). Several conventions, such as the Convention of Biological Diversity (CBD) that tackles conservation and sustainable use of biological diversity, the United Nations Framework Convention on Climate Change (UNFCCC) that tackles the problem of global warming, and the International Plant Protection Convention that tackles genetic movement of plant species (Swanson, 1997) have provided insights into various issues associated with the management of the forest ecosystem. The implementation of CBD was adopted (CBD strategic plan-decision VI/26) in 2002 (COP06), and during the world summit in 2004 (COP07), goals and sub-targets were established according to focal areas (Decision VII/30). This was re-enforced in the Bonn declaration in 2008 (COP09) in which firm decisions were taken to reduce the rapid loss of biological diversity at the global, regional and national levels to contribute to poverty alleviation and benefit life on earth before and beyond 2010 (Tim, 2010). Beside all these conventions, the biodiversity of tropical forest (lowland to Montane) has been of increasing priority due to its high level of forest depletion, and its important in species distribution, diversity and carbon storage.

The challenges to meet the loss of biodiversity are still many, especially in the vast Congo basin forest, which has an estimated area of 198 million hectares. It is the second largest tropical forest after the Amazon rainforest in South America (Bikié et al., 2000), making up almost 91% of Africa's remaining moist forests (COMIFAC, 2009). This region is one of the most diversed landscapes in the sub-region (White, 1983; Barthlott et al., 2005; Cheek et al., 2004). This tropical forest served as a huge carbon sink that could help to mitigate global climate change (Brady and De Wasseige 2010). Unfortunately, in the last two decades over 1.1 million hectares of Congo basin forest have been cleared annually (Bikié et al., 2000) giving a deforestation rate of 16.5 million hectares in the Congo basin forest area (Bikié et al., 2000). The annual average deforestation rate for Cameroon between 1980 and 2000 was 0.6% (FAO, 2007). Most of these deforestation and degradation data mentioned above were predominantly in lowland forest, and excludes the montane ecosystem, which is the subject of this study. Similarly, forest carbon fluxes on ground sampling of carbon stock are mostly available for lowland forest in the region (Djomo, 2010; Djuikouo et al., 2010; Ekoungoulou, 2014; Memiaghe et al., 2016; Djomo et al., 2016; Tabue et al., 2016). Over the years, the phytogeographical studies conducted in lowland and submontane forests, looked at species occurrence and richness (Cheek et al., 2000; Kenfack 2001; Cheek et al., 2004; Harvey et al., 2004). Only limited studies have focused on forest structure, distribution, composition and carbon stock for montane ecosystems in Cameroon (Tchouto, 1995; Tchouto et al., 1999; Sainge et al., 2014; Sainge, 2016). The present study was carried out in the wet tropical forest of the Rumpi Hills Forest Reserve (RHFR) (50-1778 m asl) and the dry semi-deciduous and savanna forest of the Kimbi Fungom National Park (KFNP) (350-1010 m asl), which falls within the continental Cameroon Mountains and spans from the coast of Mt Cameroon to the Mandara Mountains. Broadly, our study focused on the montane forest of western Cameroon. A detailed evaluation of the sampling gaps was carried out, and this subsequently led to the selection of two representative forest types – the wet tropical forest (Rumpi Hills Forest Reserve) and the dry semi-deciduous and savanna forest (Kimbi Fungom National Park) for thorough study of species distribution and diversity, biomass and carbon storage.

Firstly, this study will enable for data gathering, monitoring, and management of flora dynamics, biodiversity and ecology of the study area. It will complement the activities of the Central African Forest Commission (COMIFAC), Global Environmental Sustainability Programme (GESP), Congo Basin Forest Partnership (CBFP), and the Convention of Biological Diversity (CBD), whose collective vision is the sustainable management of forest and savanna ecosystems within its member states and the wellbeing of its inhabitants, preservation of biodiversity, and the protection of the global environment. Secondly, this study seeks to contribute and facilitate the achievement of some biodiversity targets stipulating that by 2020: about 80% of Cameroonians should be aware of the biodiversity of Cameroon, it is expected that the link and impact of human activities on the major ecosystems in Cameroon will be established, and that policy makers in Cameroon would be able to apply scientific information into biodiversity decision-making processes and management interventions (National Biodiversity Strategy and Action Plan, version II (NBSAP II), 2012).

The approach adopted in this study centred on a series of measurements undertaken in tropical forests to understand the different vegetation patterns, forest structure, composition, diversity, biomass, and carbon stock in the present day scenario and evaluates their effects and threats on land cover changes resulting from human activities. The establishment of 42 permanent sampling plots of 1 ha each, i.e., 25 sampling plots at the Rumpi Hills Forest Reserve (RHFR) and 17 sampling plots at the Kimbi Fungom National Park (KFNP), provided the rationale to understand the different ecological parameters. Recording vegetation patterns, forest structure, composition, diversity, and the estimation of carbon stock on the Cameroon Mountain range through forest inventory, are ideal ways of understanding ecological systems of the studied areas. This will enable us to answer with conviction the main research question: How does elevation and vegetation patterns influence species composition, diversity and biomass in selected wet and dry tropical forests of the Congo Basin?

The following specific research questions guided data collection

1. What are the diversity, species composition, and forest structure at different elevational gradients?
2. What is the level of above-ground biomass, and carbon stock per hectare in tropical rainforest and tropical dry semi-deciduous and savanna forest in Africa?
3. What are the extent of land cover changes, the different land use cover types, and their effects on the species composition of the RHFR and the KFNP?

1.1 Outline of the Thesis

My study sought to establish baseline data for long term ecological studies in tropical forest, focusing on the continental part of the Cameroon Mountains. This area is vast and covers approximately 37,879 km^2 in length with different mountain ranges, vegetation types and habitats. This thesis focused on the Rumpi Hills Forest Reserve and Kimbi Fungom National Park, and examined the different vegetation types and elevation gradient, forest structure, species composition, above-ground biomass and carbon. It consists of seven chapters. Chapter 1 and other five research chapters (chapters 2-6) and general discussion and recommendation in chapter 7.

In chapter 2, we discussed the botanical sampling gaps across the continental part of the Cameroon Mountains using the concept of biodiversity informatics. This was the result of a reconnaissance field survey and review of existing literature (Letouzey, 1968, 1985; Sainge and Cooper, 2014). On the basis of the findings in Chapter 2, we choosed to focus on the Rumpi Hills Forest Reserve (RHFR) and the Kimbi Fungom National Park (KFNP), both of which have significant biodiversity sampling gaps, and therefore beckons for a detailed botanical survey.

In chapter 3, we discussed the characterization, floristic composition and structure of the RHFR based on the six vegetation types (Montane, Submontane, transition submontane, mid-elevation forest, lowland basalt forest and the Atlantic Biafran forest with Caesalpiniaceae). Chapter 4 elaborates on plant community distribution, above-ground biomass (AGB) and carbon stock in four vegetation types of lowland (52-400 m), Mid-elevation (400-800 m), submontane (800-1600 m) and montane forest above 1600 m, along elevation gradient. Chapter 5 focused on floristic diversity, distribution, AGB and carbon stock across different vegetation types in the Kimbi Fungom National Park were analyze. While chapter 6 centered on the assessment of land cover changes and land use covers in the RHFR and KFNP, and chapter 7 presented a general discussion and recommendations of the study.

1.2 Literature Review

1.2.1 Forest and forest types

1.2.1.1 Definition of Forest

The definition of forest depends on the author or institution, landscape, and the different vegetation types present (Terborgh, 1992; Cameroon Forestry law, 1994; UNFCCC, 1997; FAO; 2008; GOFC-GOLD, 2008). FAO considers forest as any land of more than 0.5 hectare with trees >5 m tall with a canopy cover of >10%. However, by this definition, agricultural and urban lands are not considered as forests (FAO, 2010). Kyoto protocol on the other hand, describes "forest land" as forest with a minimum size of 0.05-1 hectare, crown cover >10 – 30%, and a minimum mature tree height of 2 – 5 m tall (UNFCCC, 1997). Forest in the context of the Government of Cameroon is any land with vegetation cover mostly composed of trees, shrubs, grasses and species of non-agricultural products (Cameroon Forestry Law, 1994). According to Terborgh (1992), forest refers to all vegetation that supports a continuous tree canopy, while nonforest refers to everything else, including open woodlands, savanna, desert scrub, and alpine grassland. For the current study, forest is define following the concept of Food and Agricultural Organization (2008).

Forest can be classified based on different vegetation types (lowland rainforest, mid-elevation, sub-montane, montane and afro-montane, wet and dry semi-deciduous, gallery, Sahel savanna, Miombo, Desert, Mediterranean woodland, and warm temperate humid), and succession (pioneer, early secondary, late secondary and climax) (Ngwa, 1981; Letouzey, 1985; Neba, 1999). Forest is such a high valued natural resource to humankind and nature because it acts as a source of medicinal plants, non-timber forest products, building materials, and food (Sainge et al., 2014). It also acts as carbon sinks, home for biodiversity, ameliorate the macroclimate of the environment, and provides other ecosystems services to millions of people (Reich, 2011).

1.2.1.2 Types of Forest

Forests are grouped into different latitudinal zones. The polar zone where only lichens and mosses are recorded on rocks and in damp places. Hence, most studies have focused on cryptograms (Bednarek-Ochyra et al., 2000; Erdau, 2001; Newsham, 2010; Putzke et al., 2015).

The temperate forest exist in two forms: the conifer forest occurring close to the polar zone, and the hardwood forest that shed their leaves in winter, occurring closed to the tropical zones. Temperate forests are mostly homogenous with few species, sparse undergrowth, absence of buttress trees and lianas. This forest is represented in Canada, Western and eastern USA, Europe and in northern Asia (Letouzey, 1986).

The tropical forest occurs in Central-South America, West-Central and East Africa, Madagascar, the Arabia and Northern Central Asia, and Australia (Terborgh, 1992; Cole et al., 2014). This forest in the Africa continent occurs in the Sahara covering the Rio de Oro, Mauritania, part of Algeria, Mali, Chad, Libya, Egypt, part of Sudan and Eritrea and the Kalahari (Letouzey, 1986). The Sahel, which is close to the equatorial forest stretches to the Sudanian savanna with mostly small trees that lose their leaves in the dry season. Some authors (Letouzey, 1986; Murphy and Lugo, 1986; Janzen, 1988; Terborgh, 1992; Molle, 2008) called the above-described forest as the dry tropical forest and the equatorial forest as the tropical rainforest.

Generally, the equatorial forest occurs between the tropics of Capricorn in the south and the tropic of Cancer north of the equator. It is also called the tropical rainforest and is the most diverse, species-rich ecosystem on earth (Letouzey, 1986; Terborgh, 1992; Molle, 2008). The tropical rainforest still fascinate many botanists, ecologists and other researchers, who have been exploring challenging questions, hypotheses, and discovery of species (Carson and Schnitzer, 2008; Bryan and Shearman, 2015). This forest is mostly heterogeneous and they lost their leaves alternatively – leaf after leaf or branch after branch. The undergrowth is dense, has trees with huge buttresses, and numerous lianas. It occurs in the Central and South America with the Amazonia forest being the largest followed by the Congo Basin Forest in Central Africa as the second largest forest block in the world. In West Africa, it stretches across Guinea, Liberia, Ivory Coast, Ghana, and Nigeria, while in Central Africa, it extends through Cameroon, Gabon, Equatorial Guinea, Congo, Democratic Republic of Congo and Central Africa Republic. It occurs in patches in East Africa: Kenya, Uganda, and Tanzania. It stretches southward to Angola and Madagascar, and in Asia it extends to Southern India, Japan, Indonesia, Papua-New Guinea, and northern Australia (Letouzey, 1986; Brandon 2014).

1.2.1.3 Tropical forests

Globally, tropical forests are mostly located close to the equator and span between the tropics of cancer (23° $28^{'}$N) and Capricorn (23° $28^{'}$S), an area of ~50 million km^2 where temperatures and rainfall are high (Terborgh, 1992; Osborne, 2000; Brandon, 2014). In general, tropical and equatorial forest falls in the same latitude within the tropics. It can be sub-divided into tropical rainforest, which is most species-diversed and species-rich, and tropical dry forest, which is species-poor, and the tropical montane forest, which cuts across rainforest and dry forest. From time immemorial, scientists and researchers have studied tropical forests, yet they remain challenging and intriguing ecosystems to study due to their immensed richness of flora and fauna, their complex structures, and the high species distribution per surface area (Whittaker, 1956; 1960; 1965; Osborne, 2000; Carson and Schnitzer, 2008; Bryan and Shearman, 2015). Despite the numerous studies carried out in this ecosystem, there is still need for research on the systematics, ecological and biodiversity aspects of these ecosystems. Broadly, tropical forest used to cover about 12% of the earth's terrestrial surface, but this has now dropped to less than 5% (600 million hectares) due to extensive deforestation and land degradation (Corlett and Primack 2011; Hansen et al., 2013).

1.2.1.3.1 Tropical rainforest

The tropical rainforest also known as equatorial forest is home to the most fascinating species of plants and animals in the world. It is fondly described as a laboratory or open library for rainforest botanists, systematists, ecologist, tourists, and experts on ecosystem services (Carson and Schnitzer, 2008; Bryan and Shearman, 2015). Most rainforest occurs within 10 degrees latitude north and south of the equator (Letouzey, 1986; Molle, 2008). However, rainforest of Central America, Mexico, Southeastern Brazil, Eastern Madagascar, Southern India, and Northeastern Australia are located outside this equatorial zone (Molle, 2008). The largest tropical rainforest belt of the world is the Amazonian forest, while the Congo Basin forest of Central Africa is the second largest forest block (Terborgh, 1992; Molles, 2008; Brandon, 2014). Collectively, it is estimated to holds ~22 tons of biomass per hectare per year compared to only 13 tons of biomass per hectare per year in temperate forest (Montagnini and Jordan, 2005).

1.2.1.3.2 Tropical dry forest

Tropical dry forests are known for their most threatened and species-poor ecosystems on the planet (Murphy and Lugo, 1986; Janzen, 1988). Nevertheless, it remains the largest ecosystem on earth (42% surface area), accounting for almost half of the world's tropical and sub-tropical forest. It occurs between 10° and 25° latitude North and South of the equator (Murphy and Lugo, 1986; Molles, 2008; Blackie et al., 2014). They are characterized by a tropical climate: annual rainfall of 500-1500 mm, 5-8 months of dry season, open forest canopies, and habitats that host some endangered species of plants, animals and insects (Janzen, 1988). They are located in the west coast of Central America, and North America, and west coast of Mexico. Most of the dry forests in South America are being converted to other land-use systems. In Africa, it is located both in the north and south of the west and central Africa rainforests, it extends to part of East Africa, the miombo woodland of southern Africa, and west of Madagascar (Molles, 2008; Blackie et al., 2014). In Asia, it occurs in India, Indochina peninsula, and in northern Australia (Molles, 2008; Blackie et al., 2014). The biome covers ~6 million Km^2, and over 50% of this land is used for animal grazing and agriculture (Ramankutty et al., 2008).

1.2.1.3.3 Tropical montane forest

Mountains formations are complex geological processes that results from earth crust movements and volcanism that are fold and elevated to the surface (Kapos, 2000; Körner et al., 2005; Richter, 2008). Globally, all the continents of the world are represented by mountain ecosystems that host tropical mountain forests (Kapos, 2000; Körner et al., 2005; Richter, 2008). Tropical montane forest are hotspots of biodiversity richness of flora and fauna, covering 32% of all protected area, with an area of 5,996.075 km^2 worldwide (Barthlott et al., 2005; Barthlott et al., 2007; Chape et al., 2008).

In Africa, they spans from Mt Loma (1947 m), and Mt Nimba (1752 m) in West Africa. Cameroon mountain range (the peak of Bioko island [2850 m], Mt Cameroon [4095 m], Mt Rata [1778 m], Bakossi mountains [Bakossi National Park], Mt Nwoanengouba, Mt Kupe, Mt Bamboutos, Mt Nlonako and Mt Oku [3011 m]). In central Africa, a few massif east of Democratic Republic of Congo extend towards Uganda (Mt Ruwenzori 5119 m; Virunga 4531 m), the East African Mountains (Mt Kilimanjaro; 6010 m), the Ethiopia mountains (3000 m), Mt Kenya (5195 m), and the Mt Mulanje (3000 m) to Mt lovely and Chela (~2400 m) in Angola. The Atlas Mountains in northwest Africa and the South Africa mountains form a consortium of the African mountains. Most of the mountains in Africa have great flora and fauna affinity (Letouzey 1986; Dowsett-Lemaire, 1989; Stattersfield et al., 1998; Richter, 2008; Molles, 2008). In the Americas, tropical mountain forests are found on the west of Central America, extending north to Alaska and to South America. This biome has a vast range of vegetation from evergreen broadleaved rich in vascular tree species, cryptogram epiphytes to species poor dry woody savanna mountains. In Asia and Europe, the mountains ranges from east to west from the Eurasian mountain ranges, including the Pyrenees, Alps, Caucasus, and the highest peak which is the Himalayas. In Australia, the mountain ranges in the east of the continent.

1.2.2 Tropical forests and Ecosystem services

Ecosystem services in tropical forest are direct or indirect benefits acquired by people living in the immediate vicinity of the tropical forest be it protected community or freelance forest (Daily, 1997; Millennium Ecosystem Assessment, 2005). These benefits can be related to ecosystem structure and functioning such as climate, topography, geology, supply of food and timber, resource availability (water and nutrients), disturbances (natural disasters such as floods and landslides), biotic communities (diverse species groups), carbon sequestration, pollination, pest control, and other human activities (Ricketts, 2004; Bunker et al., 2005). These services play vital roles in climate change strategies such as mitigation, adaptation and payment for environmental services (Turner et al., 2009; Locatelli, 2016). The world's terrestrial ecosystem can absorb approximately 3 billion tons of atmospheric carbon, 30% being anthropogenic CO_2 per year (Picogram/year, Pg/yr) (Canadell and Raupach 2008). This huge amount of carbon absorbed from the atmosphere qualifies tropical forest ecosystem as an important carbon sink in carbon sequestration. Unfortunately, the rate of deforestation in the tropics is alarming and is estimated at 0.8-2.8 Pg/yr (Baccini et al., 2012; Harries et al., 2012) with 6-17% of global anthropogenic CO_2 emitted to the atmosphere (Van der Werf et al., 2009). In order to curb the effect of deforestation, which may lead to loss of biodiversity, afforestation and reforestation have been introduced, coupled with proper farm management, soil conservation, and increase in biodiversity in farms (Uprety et al., 2012). Furthermore, good governmental policies such as curbing the effect of climate change as reported by Locatelli (2016) will be of great importance in managing and protecting loss of biodiversity within the forest ecosystem. These changes in some cases are irreversible (Ellatifi, 2005) and will mostly affect the biodiversity, composition, forest structure and ecological processes of tropical forest ecosystems.

1.2.3 Ecology of tropical forests

Ecological relationships influence the distribution, abundance and interaction of organism in their environment. The ecology of tropical forest has been studied for as far back as human history, and relying upon observed variation and predictions (Molles, 2008). Some theories or concepts tested in ecology over time are that of the Climax theory and the Holistic concept of Clement (1936), the individualistic concept of plant association of Gleason (1939), the concept of gradient analysis of vegetation invented by Whittaker (1956, 1960, 1965), the ecological principles of resource partitioning (MacArthur 1958; Connel, 1978; Grime, 1979; Davies, 1983, and Brown, 1984). These theories and hypotheses have shaped our understanding of tropical forest.

1.2.4 Threats facing tropical forests

Tropical forests are important ecosystems for many species. Tropical forests also enhance climatic processes that contribute to controlling evaporation and temperature, maintenance of vegetation types, protect soil, landslide. They hold a considerable amount of biomass and carbon as sink and sustain biological diversity and cultural activities (Raven and Williams, 1995; Laurance, 1999; Bradshaw et al., 2007; FAO, 2012). However, anthropogenic activities are the main threats to these potentials of tropical forest. Deforestation and forest degradation are the major threats, and are driven by agro-industrial agriculture, ranches, plantations, selective logging, constructions of new roads, industrialization, exploitation of natural resources, and settlement expansion (Butler and Laurance 2008; Laurance and Balmford, 2013). If the current rate of industrialization and globalization continues in developing countries like China, Brazil, India and South Africa (MEA, 2005; Laurance, 2015) then biodiversity, biomass and carbon stock losses will continue to grow. In the Cameroon Mountains, the continuous exploitation of tropical forest for small and large scale agriculture are potential threats (Kenfack et al., 2014; Kupsh et al., 2014). Remedies such as mitigations, adaptations and payment for environmental services (Turner et al., 2009) will need to be implemented, which could including curbing the expansion of agricultural land, wood extraction and infrastructural development (Norris et al. 2010). A study conducted in West African Guinea forest shows that agricultural expansion is a major drive to deforestation and degradation in Africa (Norris et al., 2010). Demenou 1997 and Eba'a Atyi et al., 2016 have demostrated that fuelwood and charcoal production for domestic and industrial uses are important causes of forest degradation.

1.2.5 Climate change and tropical forest

The concept of linking forest loss and climate change in tropical forest was enforced in 2005 under the theme "Reducing Emissions from Deforestation and forest degradation (REDD)". At the climate change conference held in Poznań 2008 (COP14 in Poland), national and regional discussions on forest emissions reductions in developing countries led to a consensus of Reducing Emissions from Deforestation and forest Degradation plus. The role of conservation, sustainable forest management and enhancement of forest carbon stocks (REDD+) was initiated during COP13 in Bali, Indonesia (European Union Institute, 2014). This initiative has created a mechanism that encompasses both reduction of emissions caused by deforestation and forest degradation, the role of forest conservation, sustainable forest management and enhanced forest carbon stocks (Dkamela et al., 2009). Clean Development Mechanism (CDM), which emerged from the Kyoto Protocol, focuses on development (including agriculture systems) that will be as little damaging to the environment as possible.

Globally, the world's forest holds ~283 billion tons of carbon in living biomass (IPPC, 2007). Land-use changes in tropical Africa are estimated at 0.3 GtC yr^{-1} of CO_2, with deforestation as the primary contributor (IPCC, 2007). Clearly, reducing deforestation will be an important step towards conserving existing forest carbon stocks. These ideas underpin the role of the Land-Use, Land-Use Change and Forestry (LULUCF) sector as a credible part of the solution to addressing climate change (UNFCCC, 2008). Hence, sustainable agriculture in the form of agro-forestry and reforestation in farms are also vital to avoid deforestation and food insecurity (Foley et al., 2005). The conference of Parties 21 (COP21) held in Paris in December 2015 was another platform to discuss issues on mitigating climate change by keeping the world's temperature rise below 1.5 degree Celsius. Article 5.1 and 12 of this conference of parties 21 stress on the conservation and enhancements of sinks, reservoirs, ecosystems and forest in other to realize increase in biodiversity, biomass and carbon and how this information can be disseminated through education, training, and public hearing (UNFCCC, 2015). The enhancement of all these parameters will give the forest its actual value and improve other ecosystem services in terms of non-timber forest products, medicine, food security, generating income, biodiversity, biomass, protection of watershed, and carbon budget.

The forest, including its vegetation and habitat is of great value to all living creatures. Incentives such as timber, fruits, vegetables, and medicial plants are important ecosystem services that are at the disposal of the local inhabitats, and the nation in income generation. The aesthetic value of tropical forest such as the beautifull waterfalls, cliffs, caves, animals and plants also attract tourist, and researchers. All these and a host of others are great sources of income, employment, and relaxation.

1.3 The Cameroon Mountains: Rumpi Hills Forest Reserve (RHFR) and Kimbi Fungom National Park

The Cameroon Mountains, part of the Cameroon Volcanic Line (Ayonghe et al., 1999; Marzoli et al., 2000; Tsafack et al., 2009), have been called by different authors as the Cameroon Line (Nono et al., 2004), the Mountains of the Cameroons (Durrell, 1958), and Biafran forests and highlands (Cronin et al., 2014). This ecological zone is composed of a chain of volcanic and plutonic isolated mountain peaks that covers about 40,877 km^2 (Tsafack et al., 2009; Sainge, 2016; Sainge unpubl. data). It is the least well-studied mountain habitat in terms of consolidated large-scale biodiversity data (Figure 1.1).

This ecoregion consist of two parts: The oceanic portion of the mountain chain, which covers about 2998 km^2 (Frodin, 2001) that runs from Pagalu (17 km^2) through São Tomé (854 km^2), Principe (110 km^2), to Bioko (2017 km^2) Island (Ayonghe et al., 1999; Frodin, 2001). The continental portion of the mountain chain covers about 37,879 km^2, and extends from Mt Cameroon (summit at 4095 m above sea level) and Mt Etinde, (commonly called small Mt Cameroon, reaching 1474 m), on the coast, through a string of peaks including Mt Mwoanenguaba (2396 m), Mt Kupe (2050 m; Morgan et al., 2011; Neba 1999), Rumpi Hills (peak at Mt Rata at 1778 m; Sainge 2016), Mt Nlonako (1875 m; Tchouto and Ebwekoh, 1999, Kenfack, 2001), Mt Bamboutos (2740 m), Lebialem Highlands (2400 m), Malap Njibanchi Hills (1947 m), and the Nkounchankap Hills (1217 m). Other important highland areas include Mt Oku (3011 m; Thomas and Achoundong, 1994; Larison et al., 1996; Cheek et al., 2000), Rhum Rock (1603 m), Nkom Wum Forest (1197 m), Kagwene Wildlife Santuary (1800 m). Mt Mambila (1821 m), Tchabal-Mbabo (2456 m), Tchabal-Gandaba (1960 m) and the Adamawa Plateau, Tchabal Ngangha (1913 m), Hossere Vokré (2046 m), and the Mandara Mts (Gèze, 1943; Larison et al., 1996; Neba, 1999; Ayonghe et al., 1999; Nono et al., 2004). The Mandaras Mts are at 900 m, with two higher inselbergs at Mokolo (1442 m) and Mogode (1224 m). This mountain chain stretches into Nigeria at the Mambila Plateau, Obudu Plateau, Mbola Hills, and Mt Shebsi, on to the Biu Plateau (Hepper, 1965, 1966; Hall and Medler, 1975; Ayonghe et al., 1999) (Figure 1.1).

Beyond this general view of the Cameroon Mountains, this study focused on the continental portion of the mountain region, specifically on the Rumpi Hills Forest Reserve (RHFR) in the South West Region and the Kimbi Fungom National Park (KFNP) in the North West Region of Cameroon. The RHFR is located in Ndian division, South west Region of Cameroon, at latitude 4.606–4.984° N and longitude 8.821–9.364° E with an elevation range of 52-1778 m at the summit of Mt Rata. It covers an area of 458.2 km^2 (Forestry Ordinance 51, 1941), and was created in 1937 to protect its huge biodiversity. It is bordered to the north by Meta village in Mundemda sub-division and Iyombo village in Toko sub-division, in the east by Dikome Balue in Dikome Balue sub-division, in the south by Nalende, Kita and Munyange in the Ekondo titi sub-division, and to the west by Boa Yenge, Motindi, Meka, and Besingi in the Mundemba sub-division (Figure 1.4). The Mundemba settlements form a corridor between the Rumpi Hills Forest Reserve (RHFR) and the Korup National Park (KNP), with two agro-industrial plantations: Pamol Plantation (PLC) Limited in the south and Sithe Global Sustainable Oils Cameroon in the Northwest of the reserve (Kupsh et al., 2014).

The Kimbi Fungom National Park is located in the Northwest Region of Cameroon at latitude 6.5-6.9° N and longitude 9.8-10.5° E with a size of 953.8 km^2 (Sainge, 2016), created on 3 February 2015 under Prime

Ministerial decree number 2015/0024/PM, and is the only national park in the region. It cuts across three divisions: Boyo, Menchum, and Donga-Mantung, covering 4 Sub-divisions: Fonfuka, Fungom, Furu-Awa, and Misaje. In the north, it is bordered by Tumbo and Tosso in Nigeria, Baji, Nser, Kpep, Furubana, Supong, Akum, Edjong and river Katsina Ala in Furu Awa sub-division. In the east by Labo, Batari, and the Dumbo cattle ranch in the Misaje sub-division, and river Kimbi, Kimbi village, Su Bum in the Fonfuka sub division. In the south; Nkang, Esu, Kundzong, Iwo, and in the west by Munkep, and Gayama in the Fungom sub-division, and Nigeria. These two compartments connect to a corridor that stretches between Nkang and Nkannye on the Fungom end to the north west of Kimbi and southwest of Dumbo cattle ranch with river Kimbi being a natural boundary between the ranch and the National Park. This park extends (Donga Mentung extension) to the north of the Dumbo cattle ranch in the Donga Mantung division.

1.3.1 Climate and hydrology in the Rumpi Hills Forest Reserve (RHFR) and Kimbi Fungom National Park (KFNP)

The climate across the continental part of the Cameroon Mountains is that of the Equatorial Cameroon type, hot and humid with two seasons. The dry and wet season varies in the amount of rainfall and temperature across the landscape from the wet rainforest in the south (Rumpi Hills) to the dry semi-deciduous and grassland/woody savanna in the north (Kimbi Fungom).

The variation in temperature along different elevations and vegetation types in the Rumpi Hills Forest Reserve (RHFR) partly explains the high plant diversity in different forest communities in this reserve (Thomas, 1996; Sainge, 2016). Temperature within the RHFR varies with the lowest at the top of Mt Rata. Nembot and Tchanou (1998) reported a temperature of 22 $^{\circ}$C and an annual rainfall of 5000 mm for the reserve. The area exhibits a short period of dry season of approximately four months (December to March). In some years, only three months (January to March) of dry season are experienced (Sainge, pers. obser.). Rainfall is mostly high in the southwest corner of the reserve (Sainge, pers. obser.). Unfortunately, until date no proper weather station occurs in this area to obtain regular climatic data for this reserve (Sainge, 2016). We assumed that due to proximity (<50 km) with Korup National Park, Mundemba whose rainfall average ~ 6000 mm per year (Chuyong et al., 2000, Chuyong et al., 2004), this reserve has >5000 mm of rainfall. Climatic data from Mundemba, which is <50 km north of RHFR gives a mean rainfall record of 5139.9 mm, radiation of 9.3 and temperature: minimum (22.3° C) and maximum (30.2° C) (Figure 1.2) over a period of eleven years.

The RHFR is a watershed for different river (R.) sources and is Cameroon's principal watershed that continues through the mountains of Kupe, Manenguba, Bakossi Mountains, Bamboutos, the Bamenda highlands, Banyo, and Adamawa plateau to the Ubangi-Shari in Nigeria (Ngwa, 1981). The rivers of this reserve flow in five directions: North into Lake Chad, via river logone; North West into river Benue, South West into the Gulf of Guinea, via River Ndian (Moriba), Moko, Meme, Mungo, and Wouri; South east into Kadei, a tributary of the Congo River, and West into Nigeria, via River Munaya, and Mbo. Hence, Rumpi Hills is a watershed for five major basins of the world: Chad, Benue, Sanaga, Congo, and Manyu Basins (Ngwa, 1981).

In the Kimbi-Fungom National Park, dry season runs from October to March, and the wet season from April to September (Sainge et al., 2014). No proper weather station is installed in the park. However, rainfall records from Nkambe (3,028 mm per year) and Ako, which has the same landscape like Kimbi Fungom and < 100 km away is 1823.8-1957.7 mm per year with an average temperature record of 21-24˚ C (Figure 1.3). This park is a watershed with numerous streams and rivers such as river Kimbi and Johga whose tributaries meet at Nkang village forming river Katsina Ala that flows through Kpep, Akum, Edjong, and Manga into Nigeria. The main rivers flowing through the park are Kimbi, Dumbo, and Johga in the Kimbi compartment. River Batum crosses Furu bana to Kpep where it flows into River Katsina Ala. Other rivers in the north are the Yamaha, Yakang, Sungsi, Ntuna, and Kenda, while in the south, River Yemene and Imea flow downward towards Nkang, and in the west, River Yaboa.

1.3.2 Elevation in the Rumpi Hills forest reserve (RHFR) and Kimbi Fungom National Park

The Cameroon Mountains is an ecological zone that cuts diagonally across southwestern Cameroon ranging from sea level at the Gulf of Guinea to the top of Mt Cameroon at an elevation of 4095 m above sea level. Within this range, isolated mountain peaks exist such as Mt Etinde (commonly called Small Mt Cameroon, 1474 m) on the coast. Mt Mwoanenguaba (2396 m), Mt Kupe (2050 m; Morgan et al. 2011, Neba 1999), Bakossi National Park (Bakossi Moutains, 1896 m), Rumpi Hills (peak at Mt Rata, 1778 m; Sainge 2016), Mt Nlonako (1875 m; Tchouto and Ebwekoh 1999). Mt Bamboutos (2740 m), Lebialem Highlands (2400 m), Malap Njibanchi Hills (1947 m), the Nkounchankap Hills (1217 m) and Mt Oku (3011 m); (Thomas and Achoundong 1994; Larison et al. 199;, Cheek et al. 2000), which is the second highest mountain in the region. Rhum Rock (1603 m), Nkom Wum Forest (1197 m), Kagwene Wildlife Santuary (1800 m), Mt Mambila (1821 m), Tchabal-Mbabo (2456 m), Tchabal-Gandaba (1960 m), Adamawa Plateau, Tchabal Ngangha (1913 m), Hossere Vokré (2046 m), and the Mandara Mountains at 900 m, with higher inselbergs at Mokolo (1442 m) and Mogode (1224 m) (Gèze 1943, Larison et al. 1996, Neba 1999, Ayonghe et al. 1999, Nono et al. 2004).

In the RHFR, the elevation range from 50-1778 m. The southern part is flat, starting from the creeks of river Moko through Munyange to Nalende, and to the northwest from Matamani through river Moriba (50 – 800 m a.s.l). West to east from Mbange, Lipenja- Mukete, Bossuga in the west to Dikome Balue, and Madie in the east, the topography is hilly with an elevation range of 800-1778 m to the top of Mt Rata.

The KFNP ranges in elevation from 240-1524 m (Sainge, 2016). Most tree species occurring in semi-deciduous, gallery, grassland and woody savanna are resistance to extreme temperatures and fire regimes.

1.4 Significance of Study

Surveys of these forest areas have been conducted in the past (Achoundong, 1995; Thomas and Thomas, 1996; Thomas, 1996, 1997; Cheek et al., 2000, 2004; Kenfack, 2001; Harvey et al., 2010; Kenfack et al., 2014); however, these were not carried out on permanent plots. Permanent plot establishment is paramount since they generate much data (Condit, 1998, Thomas et al., 2003) than temporal sample plots, used for the study of geographical distribution of species (Achoundong, 1995; Thomas and Thomas, 1996; Thomas, 1996, 1997; Cheek et al., 2000, 2004; Kenfack, 2001; Harvey et al., 2010; Kenfack et al., 2014). Studies on montane ecosystems are scant in Cameroon, which have resulted in data gaps. Furthermore, where the studies have been carried out, the findings are not readily available to the scientific community (Thomas and Cheek, 1992; Thomas and Achoundoung, 1994; Achoundoung, 1995; Cheek et al., 2000; Cheek et al., 2004; Forboseh et al., 2011). Thus, this study is setting a base for long term monitoring of the montane ecosystem that cuts across different vegetation types spanning from lowland to montane in the Rumpi Hills Forest Reserve and Kimbi Fungom National Park. Both are protected forests and the data is being hosted by Tropical Plant Exploration Group (TroPEG) Cameroon, an institution, which studies the plant biodiversity of the continental Cameroon Mountains in collaboration with students and other scientists.

The present study will contribute greatly to the current database of plant diversity of Cameroon, by providing a comprehensive checklist of plants of the Rumpi Hills ranging from lowland to montane and in the Kimbi-Fungom National Park at different vegetation types. This study will also act as a booster for other scientists and researchers who are interested in studying plant taxa and other ecological aspects in the RHFR and the KFNP. The above factors will help the scientific community, as well assist the government of Cameroon to ratify its international agreements on the Convention of Biological Diversity (CBD), Climate change, REDD, and REDD+.

Cameroon lacks effective forestry laws for montane ecosystems, i.e. the forestry law of 1994, which is under review does not place emphasis on montane ecosystems (MINEF, 1994). This study lays the foundation and benchmark for policy development and implementation. Cameroon, commonly called, “African in miniature” is rich in biodiversity and carbon storage capacity. Thus far, few studies have tried to quantify the carbon stock in Cameroon forest from lowland to montane forest and in different vegetation types (Djomo 2010, Djuikouo et al., 2010, Djomo 2013, Djomo et al., 2016, Tabue et al., 2016). This present study also examined biomass and carbon in both tropical forests from lowland to Montane of the RHFR and tropical dry semi-deciduous to savanna forest of the KFNP in Cameroon.

Cameroon has approximately 15,000 species of butterfly; 280-297 species of mammals, 10 species endemic, 27 threatened species. 542 species of fish in 179 genus, 53 families with 96 species endemic and 294 species occurring in dense humid forest; 165 species of reptiles out of the 275 species in Africa; 200 species of amphibians with 63 endemic species; 3 species of crocodile; and 190 to 200 species of batrachian. 900 species of birds, 750 species of which are residual and 150 species migratory, 11 species are endemic and 17 species are threatened. Approximately 9000 species of plants (higher plants only) with 156 species endemic, 74 threatened. Within this 9000 species of plants, 630 species have potential commercial value (Nembot & Tchanou, 1998; Foahom, 2001; GEF, 2008). Thus, results of this study will increase our knowledge on the plant biodiversity of the study area and the country at large. It will also boost Cameroon’s chances of meeting up with the goal on the Convention of Biological Diversity (CBD) in which she is a signatory.

Capacity building, education and information management are other critical components for this study. During and after the field work, over fifteen Cameroonians (students, field assistants, and community members) were trained on forest mensuration, transect cutting, plot establishment, data and specimens collections, plant specimens description, drying, sorting and identification using floras, and monographs and herbarium specimens sheets. Reports of fieldwork were sent to funders, which have been published. Manuscripts have been submitted to reputable journals for review. After presentation of this thesis, a series of seminars and conferences will be organized, and decision makers and other stakeholders will be present at these meetings for better dissemination and appreciation of the findings of this study.

1.5 Rationale of Study

Tropical montane forests are distributed in the tropics where mountains coincide with conditions sufficiently humid to permit forest growth. The vegetations of this biome are varied, and are modulated by elevation gradient, rainfall patterns, temperature, soil type, and geology. This variety and combinations of conditions have led to high species diversity in tropical mountains (Lovett, 1996; Cheek et al., 2000; Tchiengué, 2004; Cheek et al., 2004; Richter, 2008), with some specific sites recognized as biodiversity hotspots (Mt Cameroon, Bakossi National Park, etc.). This study focuses on the continental part of the Cameroon Mountains, which falls within a mega biodiversity hotspot in western African with impressive species diversity of different taxa, and with high levels of endemism (Myers et al., 2000).

Inspite of numerous biodiversity studies in Cameroon and particularly within this ecological zone (Cable and Cheek, 1998; Tchouto et al., 1999; Cheek et al., 2000; Thomas et al., 2003; Tchouto, 2004; Sainge, 2012; Sainge et al., 2014; Sainge, 2016), none of these studies has provided a broader view of the biodiversity of the continental part of the Cameroon Mountains. The Cameroon Mountains are thus relatively understudied and underappreciated. This is in contrast with other tropical montane regions, such as the Eastern Arc Mountains of East Africa and the Andes in South America (Lovett, 1996; Richter, 2008). A few studies, such as those by Cable and Cheek (1998), Tchouto et al. (1999) and Forboseh et al. (2011) focused on Mount Cameroon. Tchouto and Ebwekoh (1999) presented plants surveys of the Mwoanenguaba Mountains, Cheek et al., 2004 carried out a detailed study of plants of Mwoanenguaba, Bakossi Mountains and Mt. Kupe, and Tchiengué (2004) studied the plants of Mt Kupe. Thomas (1996) did a checklist from a reconnaissance survey of the Rumpi Hills, while Sainge (2016) studied the plants of Rumpi Hills and Kimbi Fungom National Park. Mount Oku was studied by Cheek and his team (Cheek et al., 2000), and only a preliminary botanical survey of the Lebialem Highlands has been published (Tchetcha, 2012, Fonge et al., 2013). More generally, no comprehensive overview on plants distribution and diversity exist across this broad and hyper-diverse biological landscape (Figure1.1).

Until recently, the Cameroon Mountains have suffered considerable neglect from most researchers and funders who focus on tropical rain forest, and other lowland habitats (Thomas et al., 2003; Tchouto, 2004; Djomo, 2010). This has resulted to significant data gaps, such as data on species' occurrences on the different mountains, species' distributions across elevation gradients (lowlands to Mountain tops), and different vegetation types remain poorly understood. These gaps have influenced us to study the Cameroon Mountains with focus on the Rumpi Hills Forest Reserve (RHFR) and the Kimbi Fungom National Park (KFNP) in Cameroon.

1.6 Problem Statement

A major challenge still exist in linking biological diversity, agricultural expansion, deforestation, forest degradation, biodiversity hotspots with the country land-use planning, land tenure and forestry reform strategies across the Cameroon Mountains. Estimations show that this landscape harbours 4000-6700 species of vascular plants, based on biogeographical data of species presence and absence (Cable and Cheek 1998; Cheek et al., 2000; Cheek et al., 2004; Onana and Cheek 2011; Onana, 2013; Sainge, 2016). Hence, significant biodiversity data gaps relating to different habitats, vegetation types, and elevation gradient on permanent plots sampling across the Cameroon Mountains still exists. This gap of knowledge when bridged will be paramount to policy makers and biodiversity experts to understand the different diversity patterns, biodiversity hotspots and conservation priority sites. Establishment of permanent sampling sites as was done in this study will facilitate monitoring and tracking biodiversity changes over time. In addition, this will enable us to understand the diversity, distribution, amount of biomass and carbon stock that this landscape can store as carbon sinks.

1.7 Research Aim and Objectives

The main objective of this work was to collect and analyse large-scale biodiversity data across different vegetation types and elevation gradients at the Rumpi Hills Forest Reserve and the Kimbi-Fungom National Park. This will give us the opportunity to identify, locate, explore the relationship between elevation and vegetation structure or species distribution and map the various plant species along the mountain range from lowland to montane.

1.7.1 Specific Research Objectives

1 To identify botanical sampling gaps across Cameroon Mountains, and select two gaps for a detailed study.
2 Investigate the forest structure, composition, and characterize the vegetation types across the Rumpi Hills Forest Reserve in South west Region of Cameroon.
3 Investigate the floristic diversity, distribution and carbon content across different vegetation and habitat types in the Rumpi Hills Forest Reserve.
4 Investigate the floristic diversity, distribution and carbon stock across different vegetation types in the Kimbi Fungom National Park.
5 Assess the land cover changes over time in tropical wet and dry forest of the Rumpi Hills and Kimbi Fungom forest.

1.8 Field Methods

Smaller square and rectangular plots of different sizes can be used for rapid vegetation sampling and the study of different life forms (herbs, shrubs, lianas, and trees), and later projected to per hectare. Square plots of 100 x 100 m at could cover one or two habitats, while rectangular plots of 500 x 20 m may cover different habitats (flat land, slopes, plateau, swamps, streams, rivers), vegetation types (semi-deciduous forest, gallery, grassland/woody savanna), and forest types (primary, secondary, and disturbed forest). It is in this light that our approach to study the vegetation pattern of the RHFR and the KFNP was chosen to be rectangular, using line transects of 500 x 20 m, with 25 quadrats of 20 x 20 m representing one hectare. The above method can be appreciated when appropriate tools such as remote sensing and its application in forest inventory are used.

Prior to detail field survey in the RHFR and KFNP, a thorough literature review and reconnaissance survey was carried out for both sites (Letouzey, 1985; Sainge and Cooper, 2014; Figure 1.6). All these were to identify sampling gaps, and the various vegetation types that may lead to a maximum and first hand gathering of biodiversity data (Figure 1.7). In general, our sampling design was in two parts: quantitative and qualitative sampling (Figure 1.8).

1.9 Data Analysis

Identification of specimens were carried out at the National Herbarium of Cameroon (YA) by matching specimens collected with existing herbarium sheets, and by consulting floras, published documents, and keys for the plants of the region (Hutchinson and Dalziel 1954, 1958, 1963; Vivien and Faure, 1985; Keay1989; Thomas et al. 2003; Cheek et al. 2004; Harvey et al. 2004; Harvey et al. 2010; Onana 2011, 2013). The final checklist was consolidated following the Angiosperm Phylogeny Group (APG III) classification (Judd et al. 1999; Angiosperm Phylogeny Group (APG III, 2009).

Basal Area, relative dominance, relative density, relative frequency was calculated using the formulas below. Fisher's alpha, Shannon-Wiener index (H'), and Simpson index were used as indices to compare species diversity among plant forms and elevations using the software package PAST version 2.17 (Hammer et al. 2001). This was based on 12 ha in lowland, 8 ha in mid-elevation, 3 ha in submontane and 2 ha in montane forest. Fisher's alpha was not calculated for lianas in montane forest because the values were too low. The distribution of variation in tree species diversity and carbon per hectare in different forest types was analysed using analysis of variance (ANOVA). The data were converted to binomials (0 and 1) and correspondent analysis (CA) was performed to establish the relationship among elevation, species diversity and carbon. Regression analysis was conducted with the aid of PAST version 2.17.

A non-destructive method was used to estimate above-ground biomass, and carbon stock to diameter at breast height, and wood Specific density (WD). Above-ground biomass and carbon were estimated for trees (dbh ≥10 cm) across forest types using the allometric equation of Chave et al. (2015) and tree height were estimated following Djomo et al. (2016).

Eq. (1) Basal Area (BA) = Area occupied by plant at breast height. (BA) = *pi**$(1/2\text{dbh})^2$ = *pi**$(\text{dbh})^2/4$. Basal area is the area occupied by a species.

$$\text{Eq (2) Relative dominance} = \frac{\text{Basal area of species}}{\text{Basal area of all species}} \text{ X } 100$$

$$\text{Eq. (3) Relative density} = \frac{\text{Number of individuals of a species}}{\text{Total number of individuals}} \text{ X } 100$$

$$\text{Eq. (4). Relative frequency} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \text{ X } 100$$

Frequency is the number of quadrats in which a species is found in the entire sample

Eq. (5) Importance Value Index (IVI) = Relative density + Relative dominance + Relative frequency

Eq. (6) Shannon-Weiner index (H') is the most convenient tool to measure diversity in 1-ha plots. This was achieved through the following formula:

$$H' = -\sum pilnpi$$

Where *pi* is the proportion of individual of a species (Number of individual of a species/total number of all species), ln is the natural logarithm. Thus, the natural logarithm of the number of species (lnS) is the maximum value of H'.

$$\text{Eq. (7) AGB} = 0.0559(pD^2H) \text{ (Chave et al., 2015)}$$

$$\text{Eq. (8) H} = e^{1.321+0.482\ln D+0.027\ln p} \text{(Djomo et al., 2016)}$$

Where AGB is above-ground dry biomass; *ρ* is wood density; *D* is dbh; ln is the natural logarithm, and *e* indicates the exponential function. Wood specific density was assembled from published sources such as the Global Wood Density Database (Dryad identifier: http://hdl.handle.net/10255/dryad.235) (Zanne et al. 2009), and the African Wood Density Database (http://worldagroforestry.org/sea/Products/AFDbases/WD/Index.htm) (Carsan et al. 2012). Species-specific wood densities were used for individuals identified to the species level. In cases in which species-specific wood densities were not available, mean values for the genus or family were used. For unidentified stems overall mean wood density for the data set was used (Baker et al. 2004).

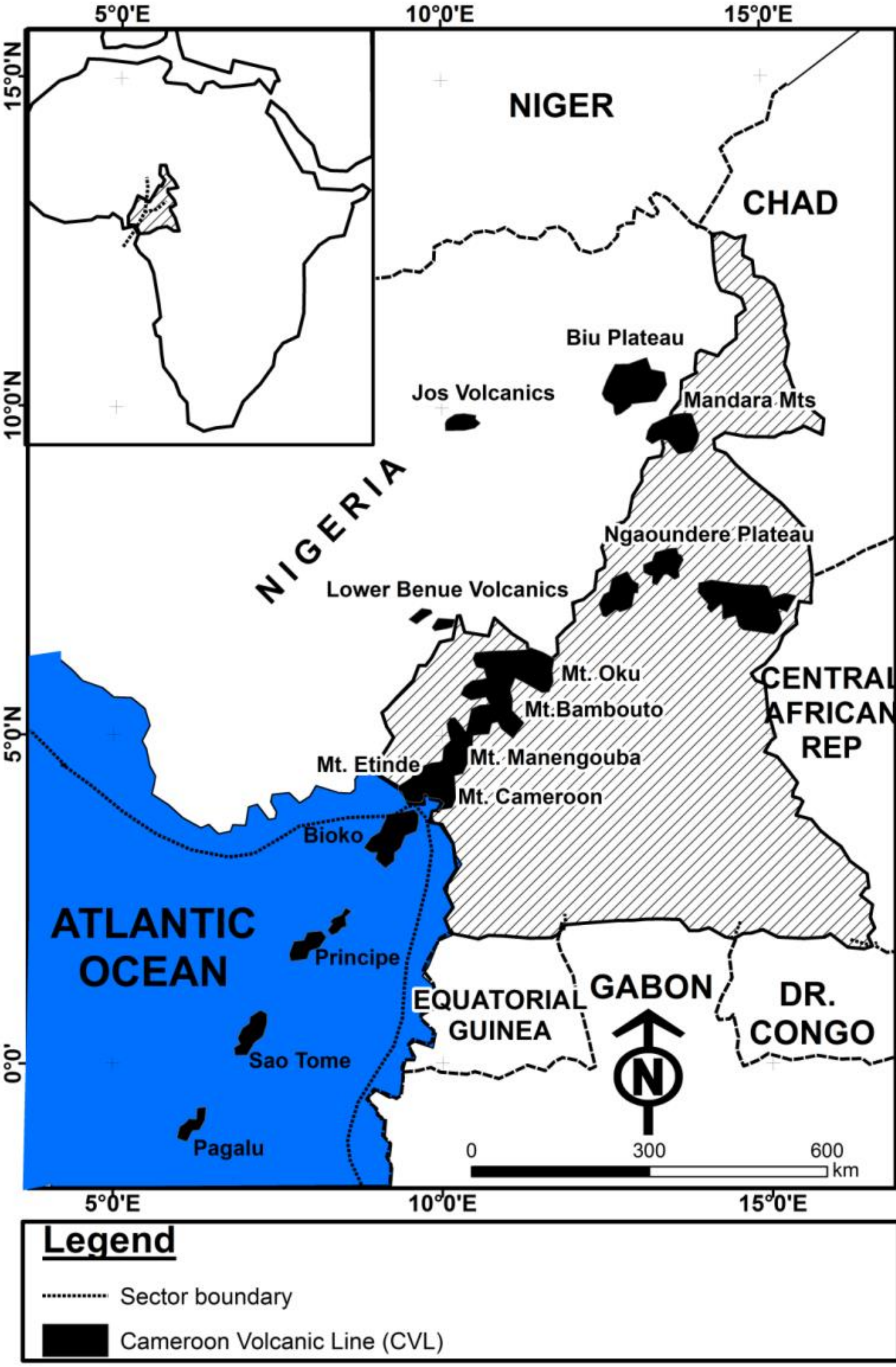

Figure 1.1 Cameroon Volcanic Line (Cameroon Mountains)

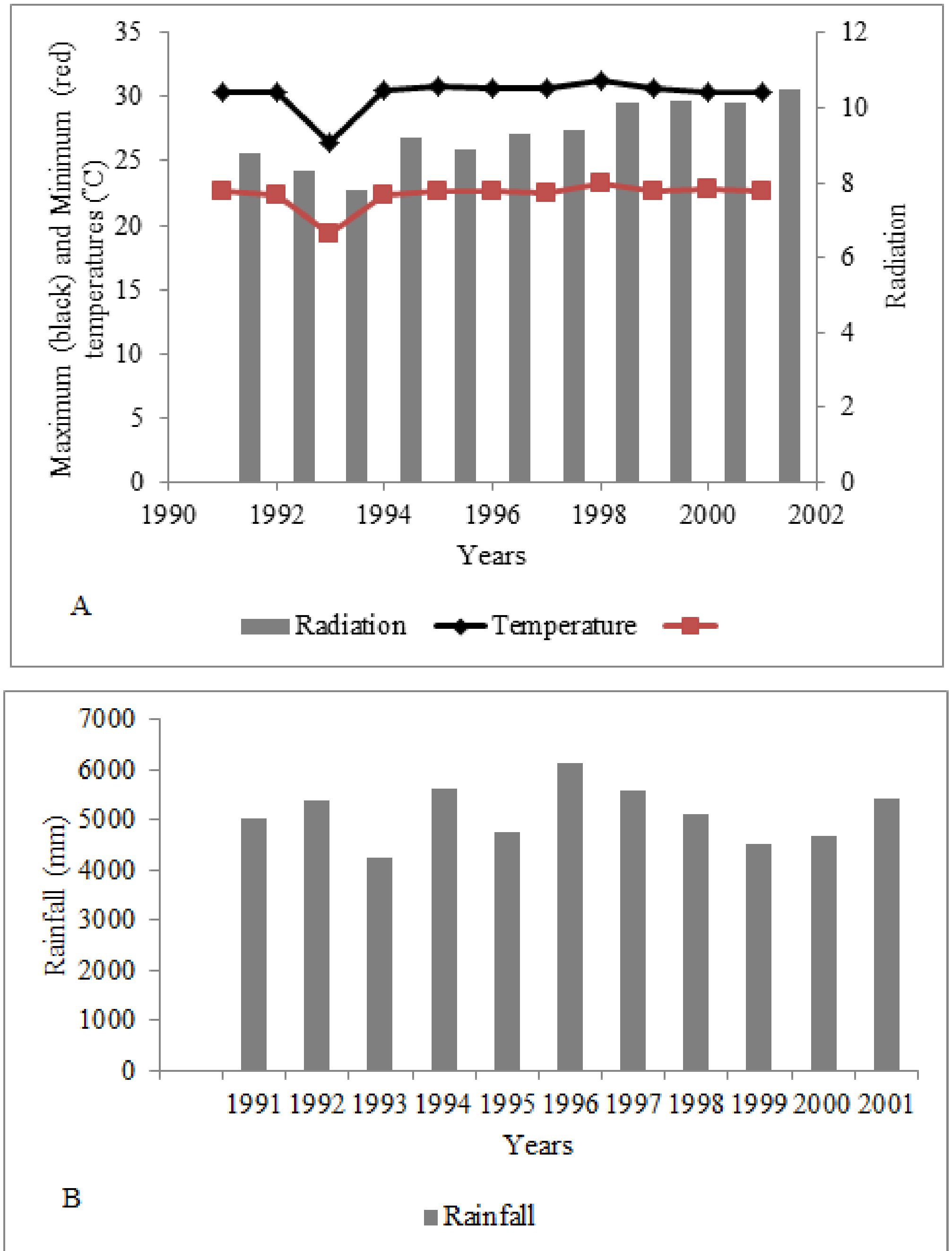

Figure 1.2. Climate representations over 10 year's (1991-2001) at Rumpi Hills Forest Reserve, Cameroon

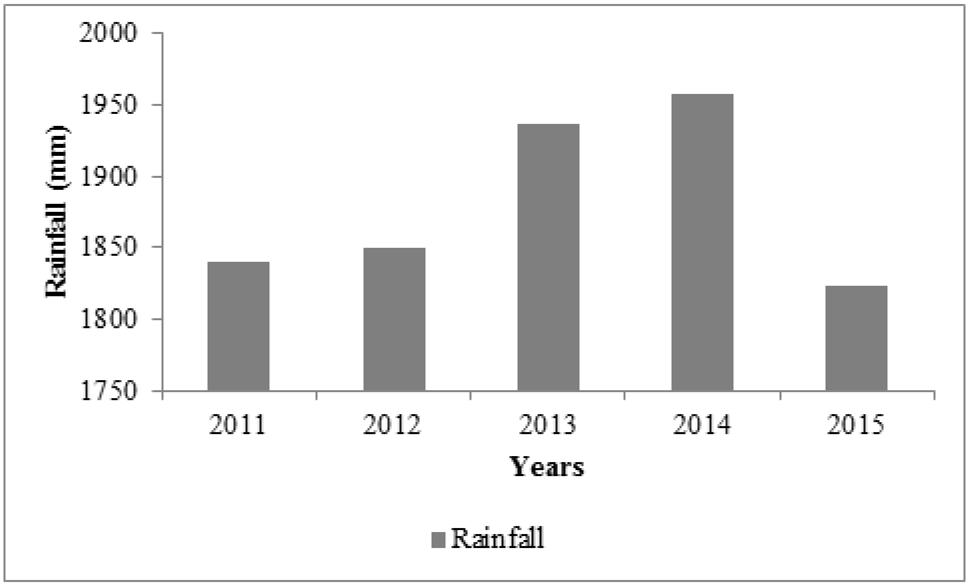

Figure 1.3 Rainfall Representations for 2011-2015 for Kimbi Fungom National Park, Cameroon (Jonathan Abe, personal communication).

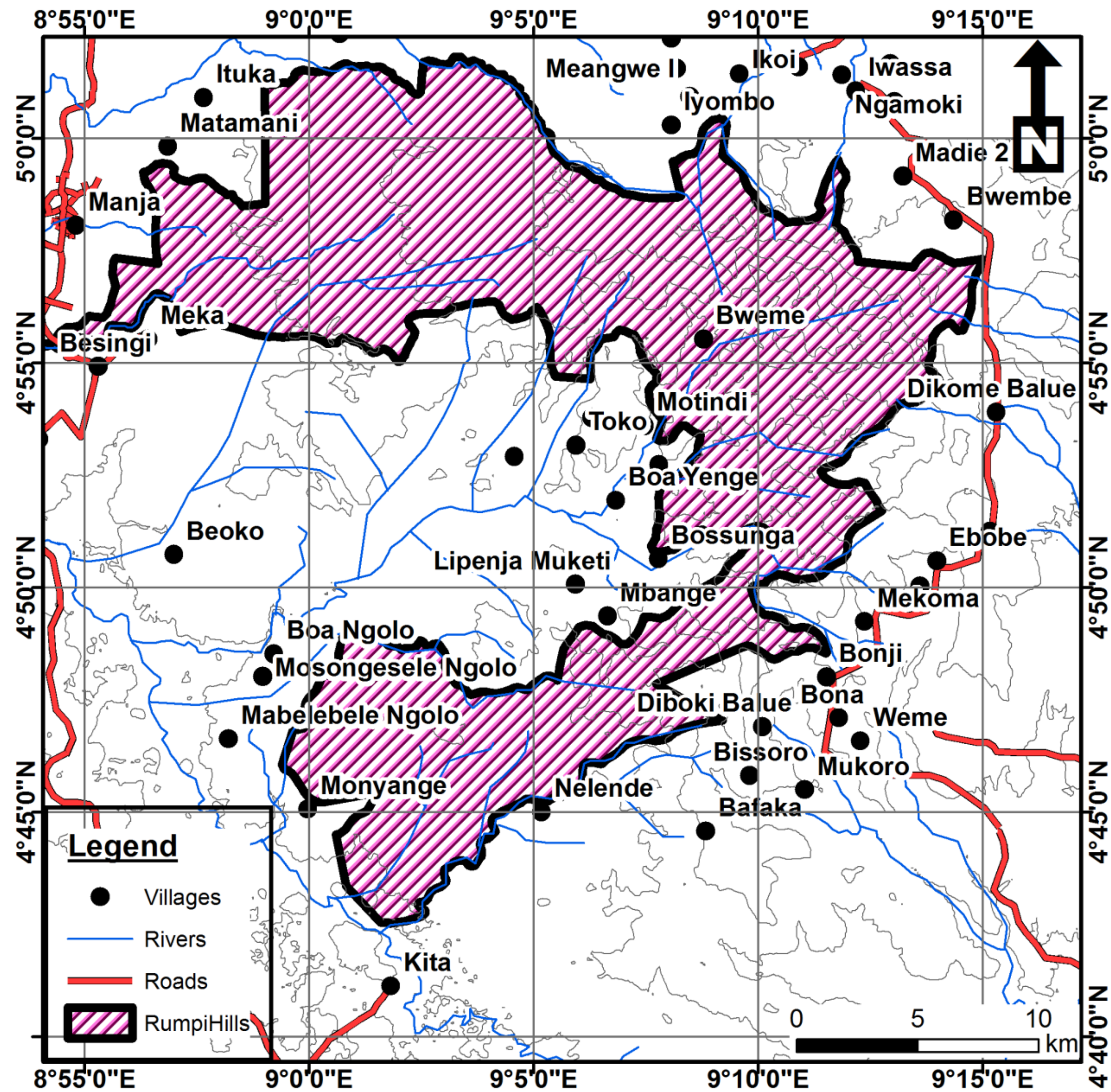

Figure 1.4 Rumpi Hills Forest Reserve Cameroon

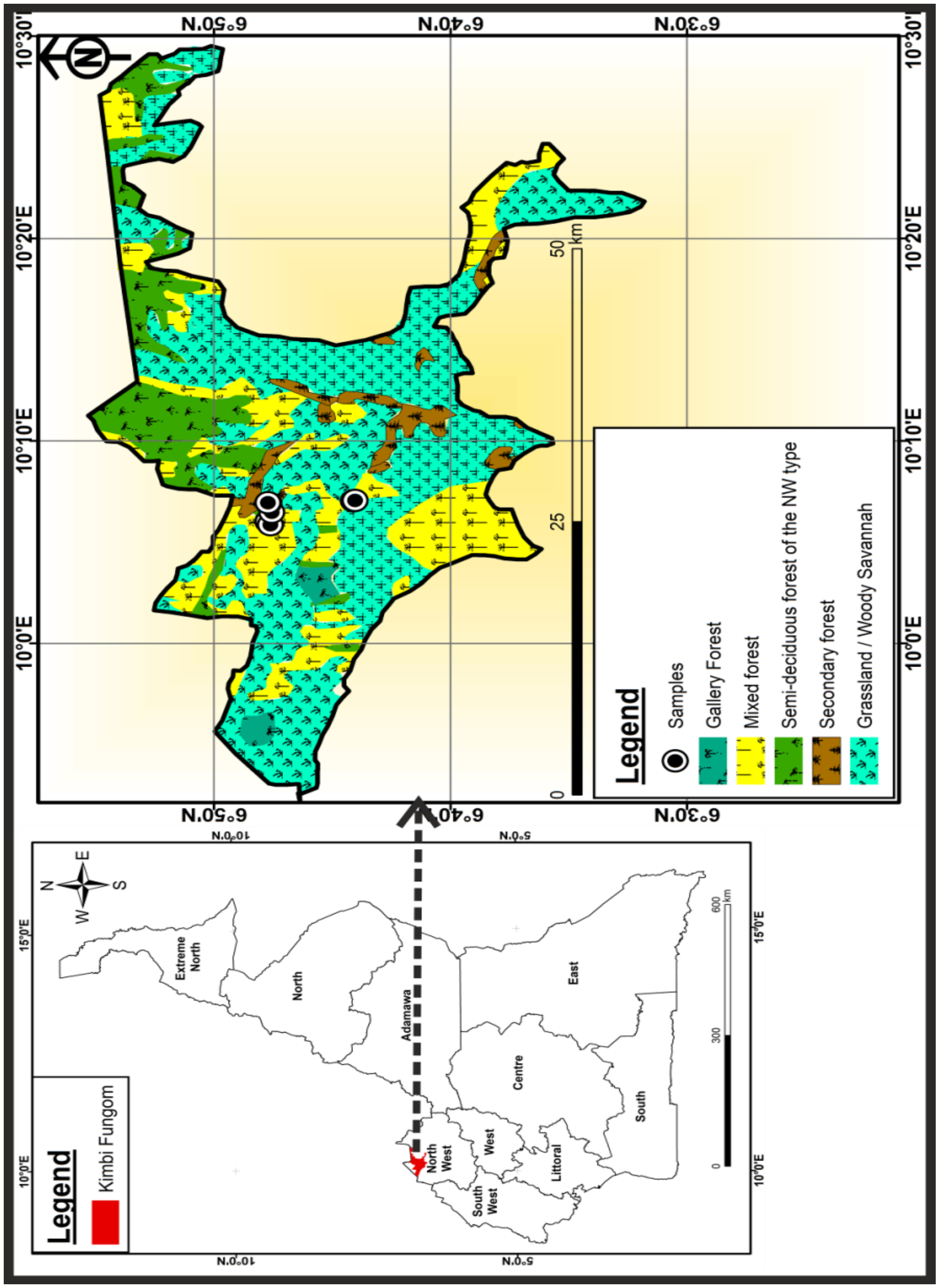

Figure 1.5 Vegetation types based on present study in the Kimbi Fungom National Park, Cameroon

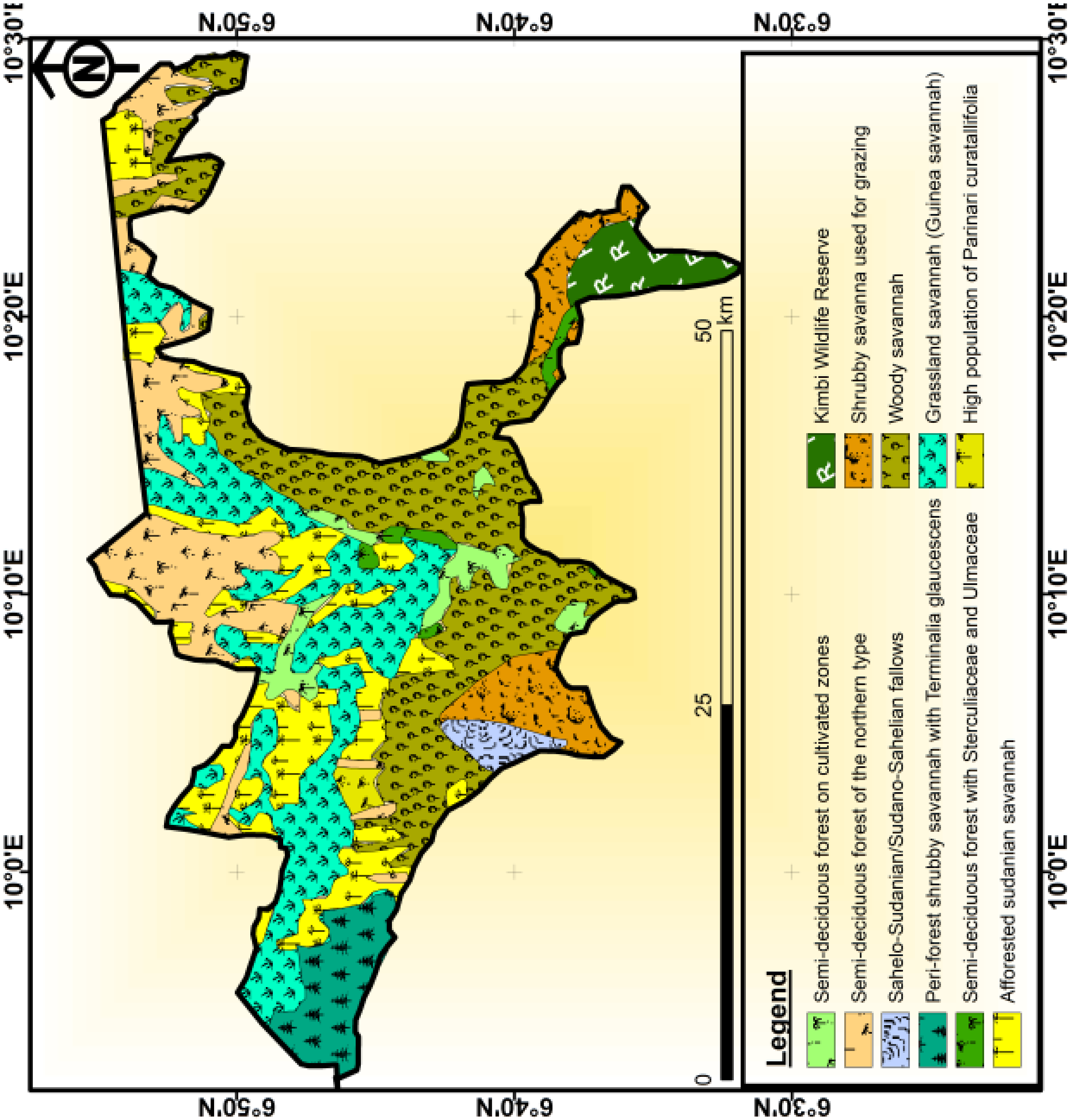

Figure 1.6 Vegetation types based on Letouzey (1985) in the Kimbi Fungom National Park, Cameroon

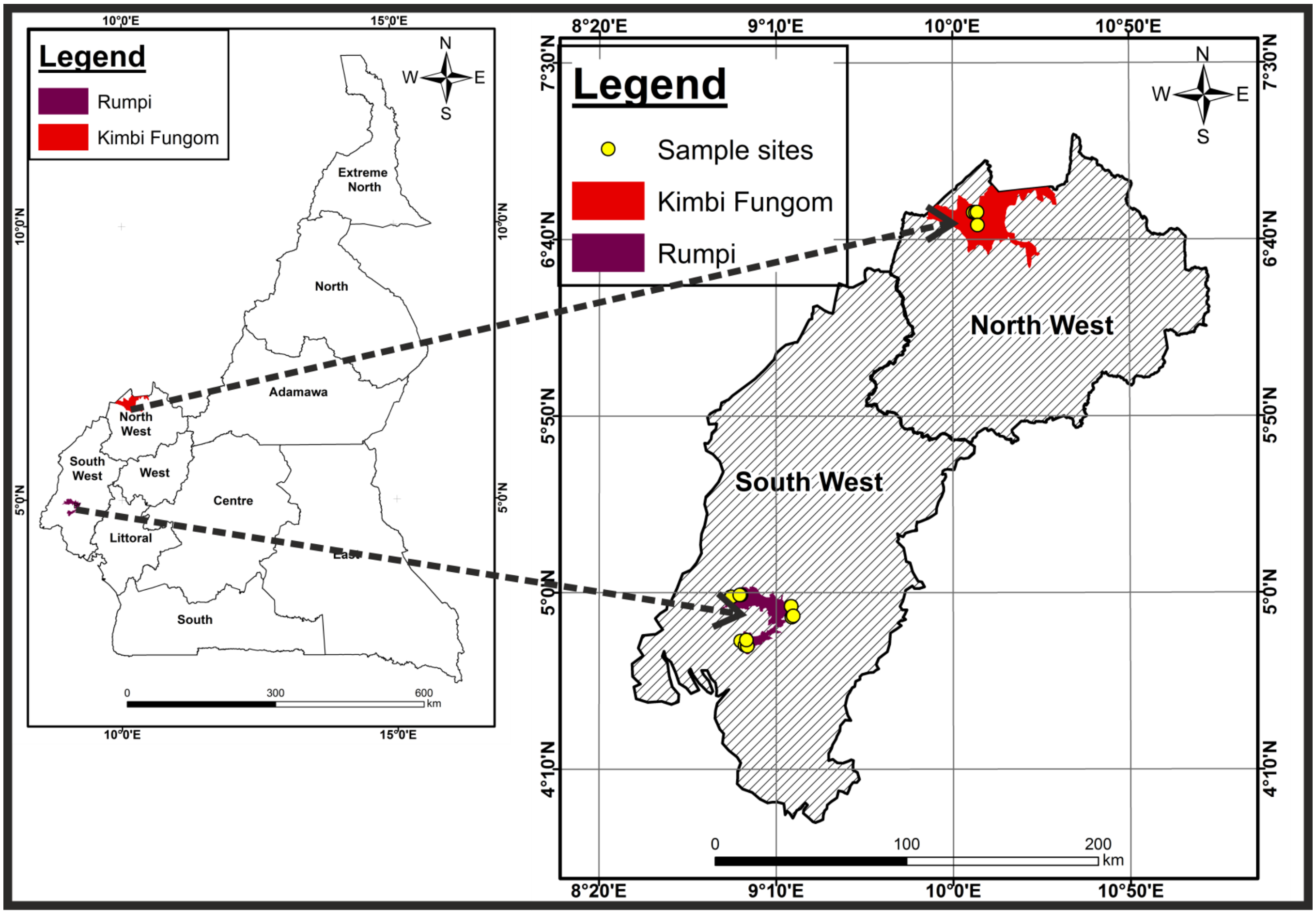

Figure 1.7 Locations of Sample Plots in the Kimbi Fungom National Park and the Rumpi Hills Forest Reserve, Cameroon.

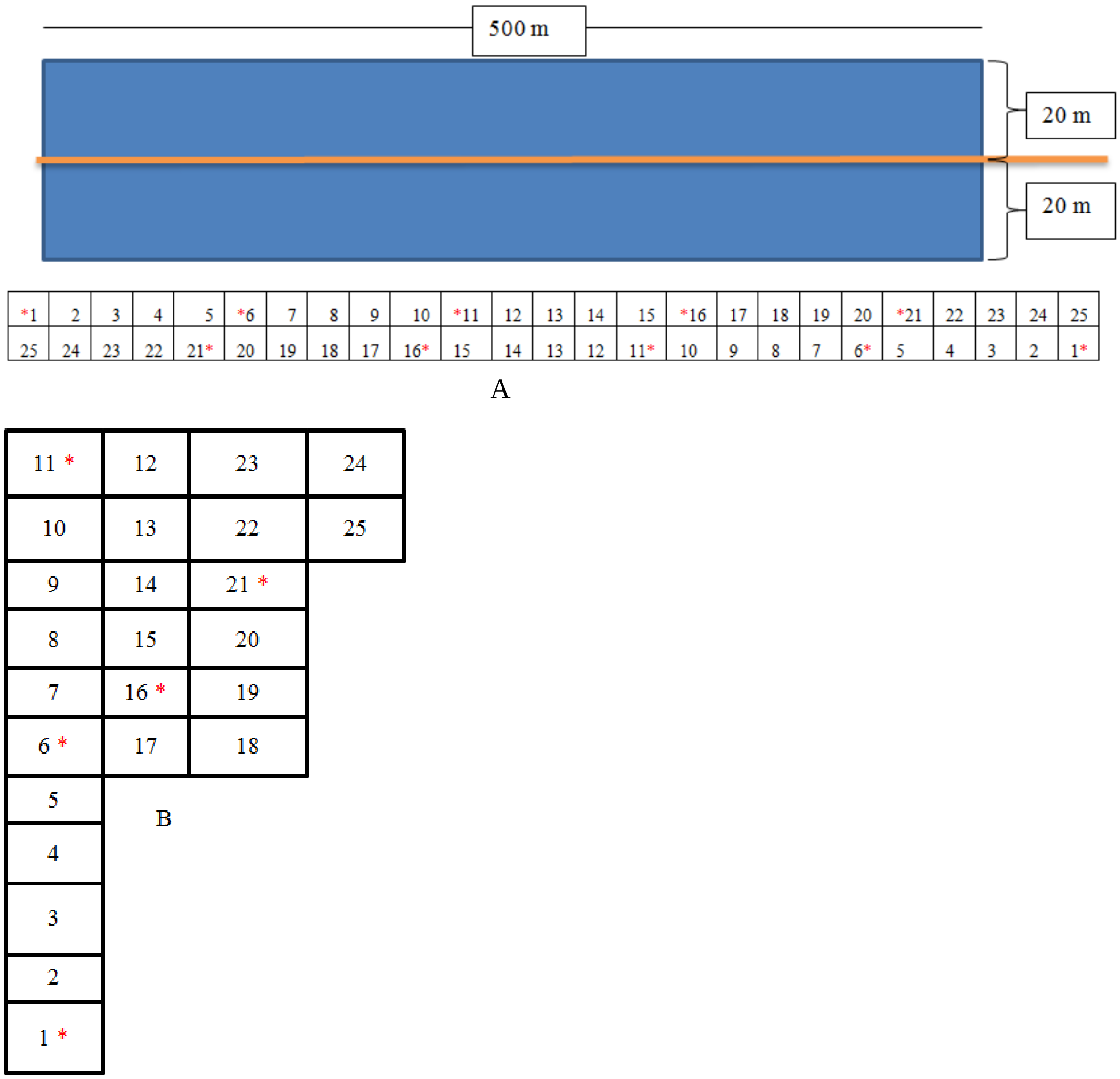

Figure 1.8 A & B. Field designs. A. Transect 500 m long (orange) in the middle of two plots, with each plot measuring 500 x 20 m. B. 25 20 x 20 m at high elevation representing 1 ha. The red asterisks at quadrat 1, 6.11,16 and 21 represents locations of nested plots of 10x10 m.

CHAPTER TWO

BOTANICAL SAMPLING GAPS ACROSS THE CAMEROON MOUNTAINS

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Preface

This chapter addresses the first objective of the study, which was to determine the botanical sampling gaps across the continental part of the Cameroon Mountains.

ABSTRACT

With the emergence of a new field, biodiversity informatics, an important task has been to evaluate completeness of biodiversity information that is existing and available for various countries and regions. This paper offers a first and very basic assessment of sampling gaps and inventory completeness across the Cameroon Mountains. Because digital accessible knowledge is severely limited for the region, we relied on qualitative evaluations of inventory completeness, supplemented by large amounts of data from the National Herbarium of Cameroon (YA) database. Our findings shows that detailed botanical inventories have been developed for Mt Cameroon, the Kupe-Mwoanenguba Mountains, Mt Oku, and the Mambila Plateau, leaving substantial geographic and environmental coverage gaps corresponding to Rumpi Hills, Mt Nlonako, Kimbi Fungom National

Park, Bali and Bafut Ngemba, Mt Bamboutos, Kagwene, and Tchabal Mbabo. This gap resulted in the selection of Rumpi Hills and Kimbi Fungom National Park for a detailed survey. This paper provides a roadmap for a comprehensive botanical survey for this region. Completing this survey plan, the resulting data will allow researchers to track changes in biodiversity and identify priority areas for conservation on the various mountain ranges that make up this important biodiversity hotspot. We here conclude that the digital Accessible knowledge for Cameroon is limited.

Keywords: biodiversity informatics, primary biodiversity data, sampling gaps, inventory completeness, mountains

2.1 INTRODUCTION

The Cameroon Mountains, also known as the Cameroon Line (Nono et al., 2004) or Cameroon Volcanic Line (Ayonghe et al., 1999; Marzoli et al., 2000), is comprised of a chain of isolated volcanic and plutonic mountain peaks that covers ~40,877 km^2, stretching from Pagalu Island in the Gulf of Guinea to the Mandara Mountains in the interior. The oceanic portion of the mountain chain covers ~2998 km^2 in the form of four major islands: Pagalu, 17 km^2; São Tomé, 854 km^2; Principe, 110 km^2; Bioko, 2017 km^2 (Ayonghe et al., 1999; Frodin, 2001). The continental portion of the mountain chain is broader, covering ~37,879 km^2, extending from Mt Cameroon (4095 m) and Mt Etinde (commonly called Small Mt Cameroon, 1474 m) on the coast, through a string of peaks, extending to the north and east into the interior (Figure 1). The greatest part of the Cameroon Mountain chain lies within Cameroon, which is the focus of this study, but it extends into adjacent Nigeria at the Mambila Plateau, Obudu Plateau, Mbola Hills, Mt Shebsi, and the Biu Plateau (Hepper, 1965, 1966; Hall and Medler, 1975; Ayonghe et al., 1999, Figure 2.1). Numerous protected areas include portions of the Cameroon Mountain chain, including Mt Cameroon National Park, Bakossi National Park, Santchou Forest Reserve, Kimbi Fungom National Park, Mbam et Djerem National Park, and Vallée de la Mbéré National Park. However, although endemism is high in the region overall, particularly for plants, these protected areas were established based on minimal biodiversity information, and no quantitative conservation prioritization has been develop for the region.

Botanists have invested considerable energy in basic surveys of the plants of this region. Mt Cameroon (Thomas and Cheek, 1992; Tchouto, 1995; Cable and Cheek, 1998; Tchouto et al., 1999; Cheek et al., 2006; Onana, 2010a, 2010b, 2011, 2013). Mt Kupe, Mt Mwoanenguba and Bakossi National Park (Thomas, 1993;

Tchouto and Ebwekoh, 1999; Cheek et al., 2004; Tchiengué, 2004). Mt Oku (Thomas, 1986a, b; Mbenkum and Fisey, 1992; Tame and Asonganyi, 1995; Asonganyi, 1995; Maisels and Forboseh, 1997; Cheek et al., 2000; Maisels et al., 2000; Tame and Thomas, unpubl. data) and the Mambila Plateau (Hepper, 1965 and 1966) have all been the subject of detailed, and reasonably complete botanical surveys. Sites for which at least some information exists include Rumpi Hills (Thomas, 1996; Sainge, 2016), Mt Nlonako (Kenfack, 2001), Lebialem highlands (Harvey et al., 2010; Tchetcha, 2012; Fonge et al., 2013), Bali and Bafut Ngemba (Harvey et al., 2004; Cheek et al., 2010), Tchabal Mbabo, and the Adamawa Plateau (Thomas and Thomas, 1996; Chapman et al., 2004). Areas with scanty botanical information are Mt Lefo, Malap Njibanchi Hills, Nkounchankap Hills, Kagwene, and Faro National Park.

More generally, however, the Cameroon Mountains hold tropical montane forests known internationally for their rich flora and high levels of endemism, combined with high levels of threat (Myers et al., 2000; Onana and Cheek, 2011). This biome is part of a mega-hotspot of Western Africa cited as having impressive species diversity and hosting numerous endemic taxa (Mittermeier et al., 1999; Myers et al., 2000; Marchese, 2015). Still, only scanty primary biodiversity data are available for the region, and—to our knowledge—no quantitative analysis of conservation priority has been develop regarding any taxon for the region. As such, a detailed evaluation of gaps in knowledge regarding the plants of this region is presented here to lay a foundation for more detailed inventories and analyses in terms of structure and composition, species diversity, and richness. Because major sectors of the botanical knowledge of this region remain in non-digital or non-shared formats, our analyses are necessarily qualitative at this point, in hope of transition to digital and quantitative in coming years. The sampling gaps in this region were Rumpi Hills, Mt Nlonako, Kimbi Fungom National Park, Bali and Bafut Ngemba, Mt Bamboutos, Kagwene, and Tchabal Mbabo. These resulted to the selection of Rumpi Hills and Kimbi Fungom National Park for detailed studies. The main goal for this activity is to generate a plant database for this region in the future, understand its forest structure, composition, biomass and the carbon that its can holds per hectare in the different vegetation types.

2.2 MATERIAL AND METHODS

We focused on montane areas with elevations >1600 m, and also considered information from those areas down to 600-1000 m. This was due to occurrence of endemics >1600 m and the high diversity and forest structure at 600-1000 m. However, many species found around 1000 m were also distributed over 1500 m up to 1800-2000 m elevation. Data on previous botanical surveys across the region were derived from published documents, floras, monographs, reports (Hutchinson and Dalziel, 1954, 1958, 1963; Vivien and Faure, 1985;

Keay, 1989; Thomas et al., 2003; Cheek et al., 2004; Harvey et al., 2004; Harvey et al., 2010; Onana, 2011, 2013), and the databases of the National Herbarium of Cameroon (YA) (Holmgren et al., 1990). From the latter source, 23,667 records were assessed for accuracy, and records falling in highland areas extracted. This information was summarized in spreadsheets that included latitude, longitude, elevation, number of data records, and number of species documented, but numbers of records and species were unconvincingly low; the bulk of existing information for the plants of the region remains in non-digital formats. As a consequence, we resorted to a qualitative evaluation (our consensus opinion) of completeness of the inventory of each area, as 0 = never visited, 1 = incidental data, 2 = some records, and 3 = a published 'flora' or otherwise comprehensive summary that appears to be reasonably complete.

We produced a spatial dataset summarizing the distribution of montane areas within the Cameroon Mountains from the GMTED2010 digital elevation model (DEM; http://topotools.cr.usgs.gov/gmted_viewer/), at a spatial resolution of 7.5" (~230 m at the Equator). We reclassified the raw DEM into elevational intervals of 0-1000 m (lowlands), 1000-1600 m (foothills), and >1600 m (montane areas), and created vector-format shape-files of areas >1000 m and >1600 m to facilitate analysis. Finally, for analysis, we further subdivided two large areas into smaller subunits based on relatively low valleys that were nonetheless above 1600 m. We focused on areas with completeness at level 3, which we considered at least in a preliminary sense, as well sampled.

Established which polygons were to be considered as sampled, the shape file were converted to raster (geotiff) format using custom scripts in R (R Foundation for Statistical Computing, 2004). This raster coverage was the basis for our identification of gaps, the proximity (raster distance) function in QGIS (version 2.4) was used to summarize geographic distances from all montane sites to those that are well sampled. 5000 random points across the Cameroon Mountains were plotted to create a parallel view of environmental difference from well sampled areas, (i.e., in areas >1600 m), and used the point sampling tool in QGIS to link each point to the geographic distance raster, and to raster data layers at 30" (~1 km) spatial resolution summarizing annual mean temperature and annual precipitation from the WorldClim climate data archive (Hijmans et al., 2005). Rescaled values of each environmental variable to the overall range of the variable as $(x_i - x_{min}) / (x_{max} - x_{min})$, where x_i is the particular observed value in question, such that each environmental variable varied only 0-1. For all points not falling in well-sampled areas (geographic distance = 0), Euclidean distance were calculated in the two-dimensional climate space to all points falling in well-sampled areas; minimum value of these Euclidean distances as the environmental distance to a well-known area were identified (Sousa-Baena et al., 2014). Finally, the environmental distances were imported into QGIS, and linked back to the random point shape-file.

2.3 RESULTS

Among the 23,667 digital herbarium records from YA, 13,609 records correspond to highlands within the Cameroon Mountains region, representing 3995 species (Figure 2.3). Data generated from published papers, reports, floras, and monographs correspond to 3314 records representing 1175 species. The analysis shows significant sampling gaps (sites with few or no sampling history) along this mountain chain, ranging from the Rumpi Hills, Mt Nlonako, the Lebialem Highlands west of Mt Bamboutos, and the Bamenda Highlands (extending to Tchabal Mbabo and the Adamawa Plateau). Our explorations of the YA database (Figure 2.3) indicated that data is sparse for individual montane areas, preventing quantitative analysis (Colwell and Coddington 1994). As a result, qualitative analysis was used.

A broad view of the Cameroon Mountains region with our qualitative inventory summary is presented in Figure 2.1. Four highland sites were identified whose inventory are considered well known: Mt Cameroon, Bakossi landscape (Mt Kupe, Mt Mwanenguba and the Bakossi National Park), Mt Oku (Kilum-Ijim ridge), and Mambila Plateau; Figure 2.4). Five sites for which some information exists (Rumpi Hills, Mt Nlonako, Bali Ngemba, Bafut Ngemba, and Tchabal Mbabo), and two sites that remain poorly known (Mt Bamboutos, and Adamawa Plateau). In five sites, there was no indication of any previous botanical work (Kagwene Forest, Nkom-Wum Forest Reserve, Faro Reserve, Kumbo Area, and Rhum Rock). Geographically, the sites most distant from well-known sites were the Adamawa Plateau, and Tchabal Mbabo (Figure 2.2).

Interestingly, in terms of environmental distances, the sites most different from well-known sites were quite different from the list based on geographic distances. Specifically, the area most distinct in terms of environments was the Rumpi Hills, Mt Nlonako, and the Lebialem Highlands, which is west of Mt Bamboutos. These sites are centrally located in the Cameroon Mountains chain, and are geographically relatively close to well-known sites (Figure 2.4, Table 2.1).

2.4 DISCUSSION

The continental part of the Cameroon Mountains with focus on Cameroon is one of the most diverse sites in Africa, and has been classified as a biodiversity hotspot (Cheek et al., 2000; Cheek et al., 2004; Barthlott et al., 2005). This region is the only part of Central Africa with an elevational range from sea level to over 4000 m, and holds a high diversity of plants > 6000 species out of the almost 9000 species in Cameroon (Cable and Cheek 1998; Cheek et al., 2000; Cheek et al., 2004; Onana and Cheek, 2011; Onana, 2011). At the continental level, this region has great affinity in species composition with other montane sites such as the mountains of

West Africa (e.g., *Bersama abyssinica*; Cheek et al., 2004) and East Africa (e.g., *Polyscias fulva, Strombosia scheffleri, Schlefflera abyssinica, Alangium chinense, Maesa lanceolata*; Dowsett-Lemaire, 1989; Thomas and Thomas, 1996; Cheek et al., 2000; Cheek et al., 2004; Sainge 2016).

This region holds >200 species of plants that are considered as threatened, which is the highest in Cameroon and perhaps the highest in West and Central Africa (Cheek et al., 2004; Onana and Cheek, 2011), with >80 species endemic (Cheek et al., 2004; Franke, 2004; Sainge et al., 2005; Sainge et al., 2010; Sainge, 2012; Sainge, 2016). Examples of threatened and endemic plant species occurring in the region are *Afrothismia saingei*, *A. fungiformis*, *Rhaptopetalium geophylax*, *Schefflera manni*, *Syzyzium staudtii*, *Ixora foliosa*, *Gambeya korupensis*, *Deinbollia angustifolia*, and *Begonia pseudoviola*. The region hosts 3 of the 7 genera endemic to Cameroon (*Hamilcoa, Medusandra, Platytinospora*); finally, the only endemic family in Cameroon (Medusandraceae) is represented here, with its two species: *Medusandra mpomiana* and *M. richardsiana* (Cheek et al., 2004; Onana, 2013).

However, this landscape has been visited and sampled by botanist mostly in terms of surveys of species' occurrences, and most of the data are still in non-digitized formats. This information thus remains inaccessible to scientists with interest on African biodiversity, particularly those based in Africa. We attempted to develop two relatively independent views of botanical inventory completeness across the Cameroon Mountains region. Our attempt at a quantitative analysis (after Sousa-Baena et al., 2014; Idohou et al., 2015; Kouao et al., 2015) was stymied by the small numbers of primary occurrence data that are available for the region, and by the large proportion of such data that remains in non-digital formats in institutions in Europe. As a consequence, in our second effort, we used a literature review to detect and identify landmark studies that have documented Cameroon Mountain sites in good detail (Mt Cameroon, Mt Kupe, Mt Mwoanenguba, Bakossi National Park, Mt Oku, and Mambila Plateau). We found little or no access to the primary data that underlay those publications and that document the individual specimens collected. The 13,609 occurrence data points from the Cameroonian National Herbarium corroborated this view: good numbers of occurrence points concentrated in sites identified as well sampled in the qualitative analysis.

In a bigger view, the online digital accessible knowledge (DAK; Sousa-Baena et al., 2014) for Cameroon remains entirely too sparse. With a conservative estimate of ~155,000 specimens (and likely many more) collected to date in the country (Onana, 2011), only ~65,000 (41.9%) are represented in the database of YA (J.M. Onana, unpubl. data.). This gap exists because large-scale collections made from the colonial era into the

1950s and subsequent decades are deposited in major herbaria in Europe and North America; although not without exceptions, most of these collections remain undigitized and largely inaccessible to the broader community interested in African biodiversity. Although some of the big data-holders have begun steps to make information available (Le Bras et al., 2017), the DAK impediment thus remains significant, with Kew Gardens being the single largest data holder from which no DAK are available. This blockage of information flow must be resolved if any quantitative analyses of biodiversity pattern, subregional endemism, and conservation priority are to be developed for the region.

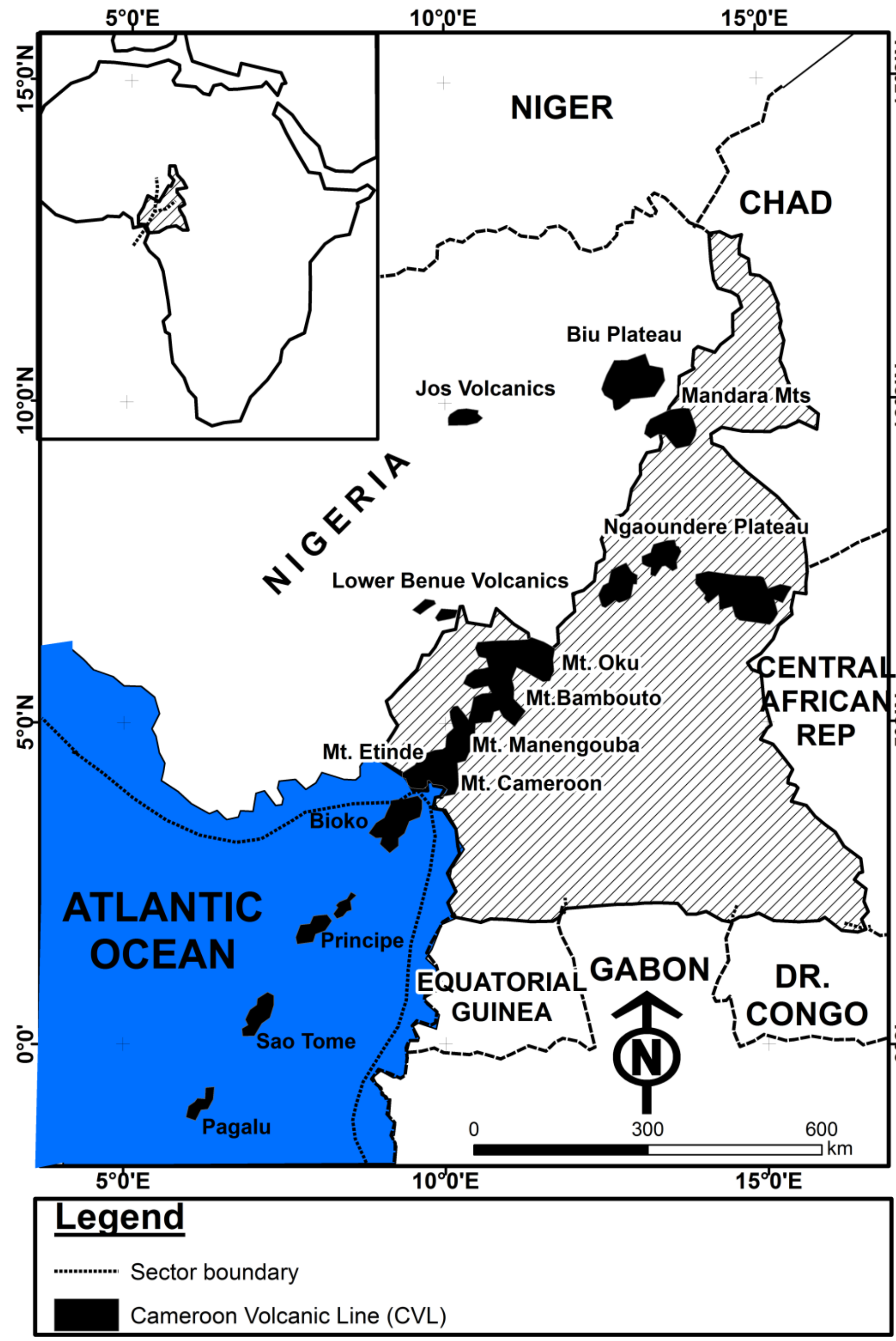

Figure 2.1. Diagrammatic representation of the Cameroon Mountain chain, extending from islands in the Gulf of Guinea to the coastal Mt Cameroon, and inland along the Cameroon-Nigeria border.

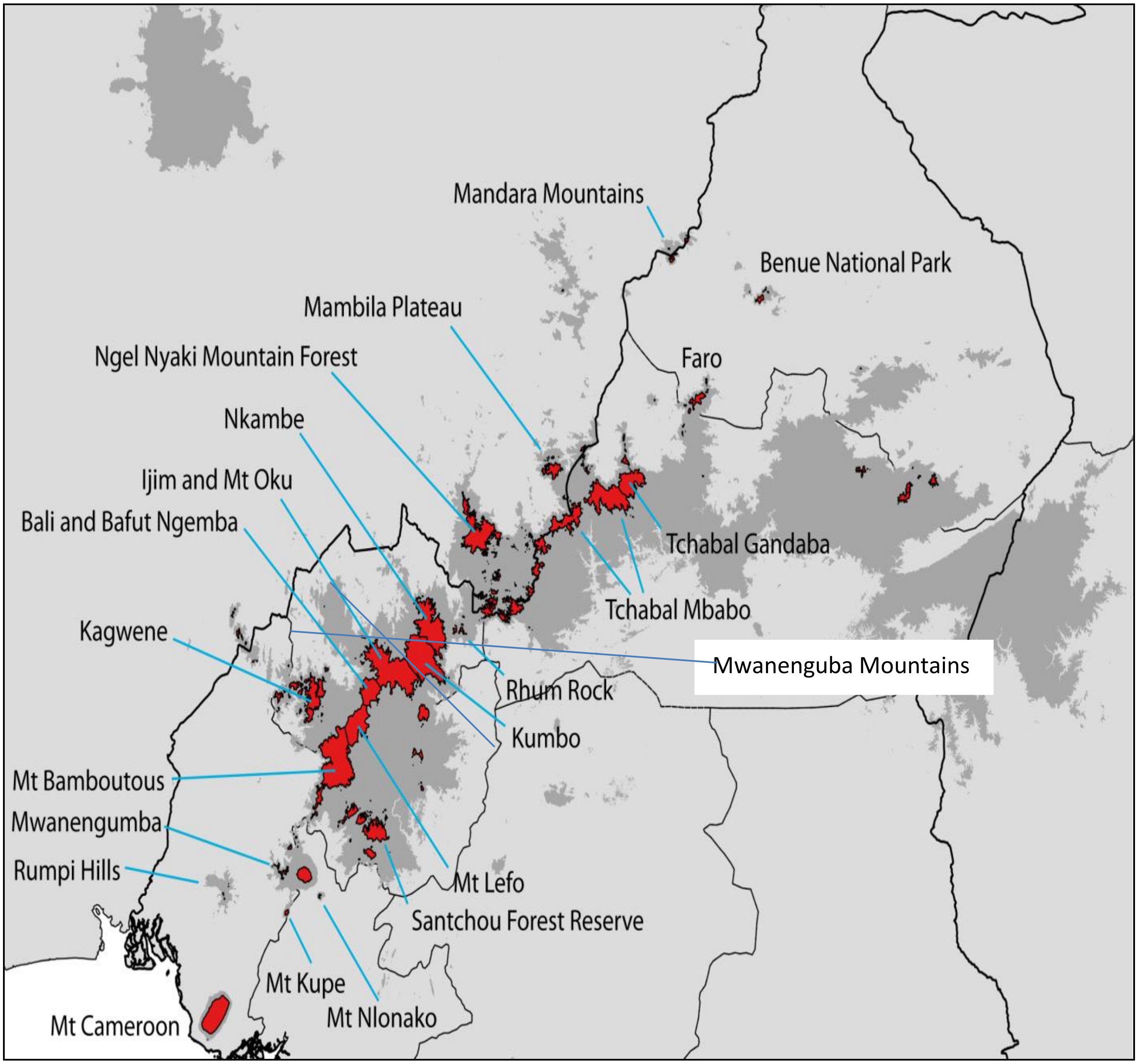

Figure 2.2. Summary of highland areas in the continental portion of the Cameroon Mountains region. Areas above 1000 m elevation are shown in darker gray shading. Areas above 1600 m are shown colored red and outlined in black. The more important such highland areas are labeled for reference to the text.

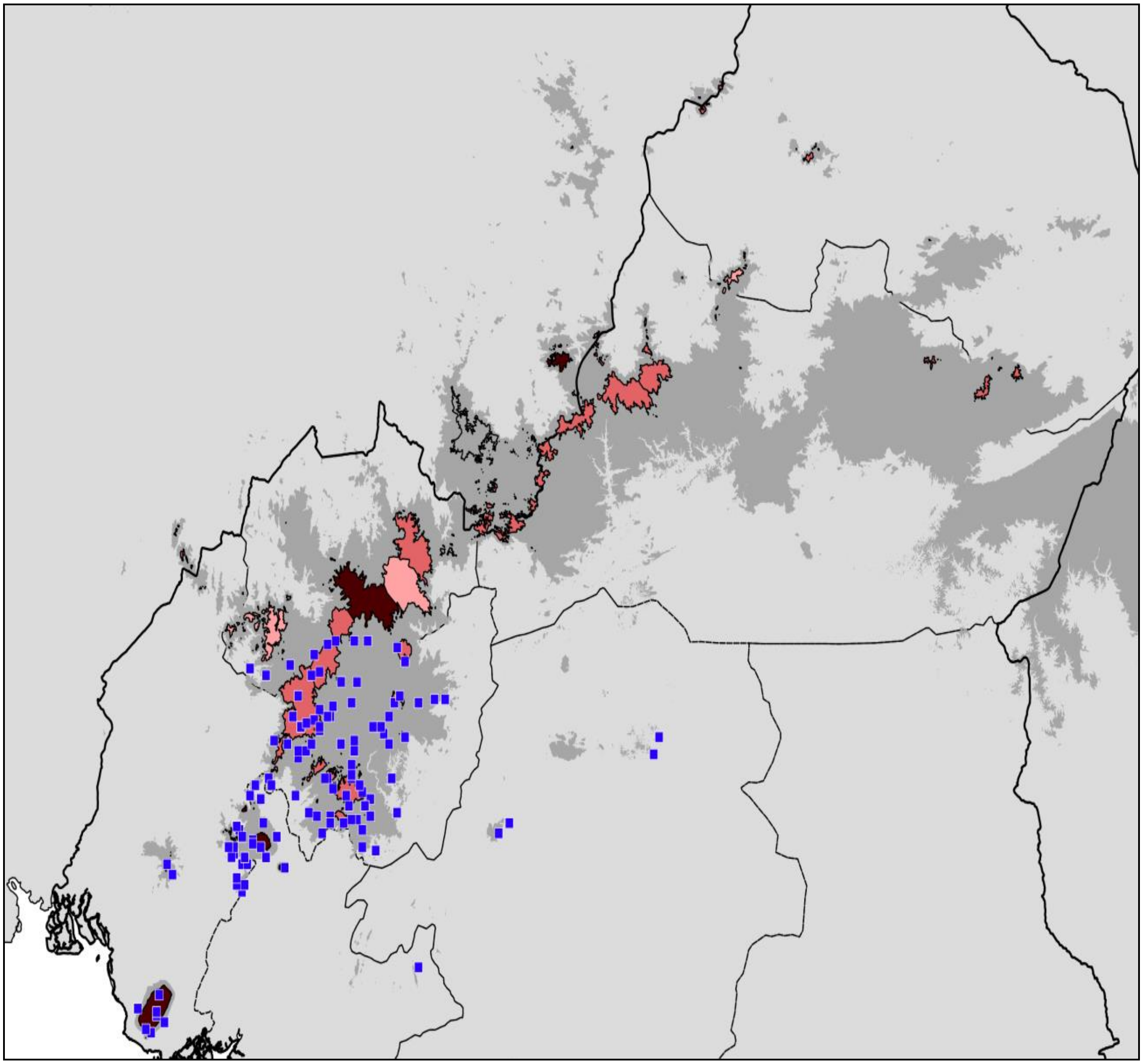

Figure 2.3. Map of the continental portion of the Cameroon Mountains region, showing points sampled in the YA collections in blue. The different highland areas are indicated as well-sampled (dark red), some sampling (medium red), some information (light red) or no information (gray).

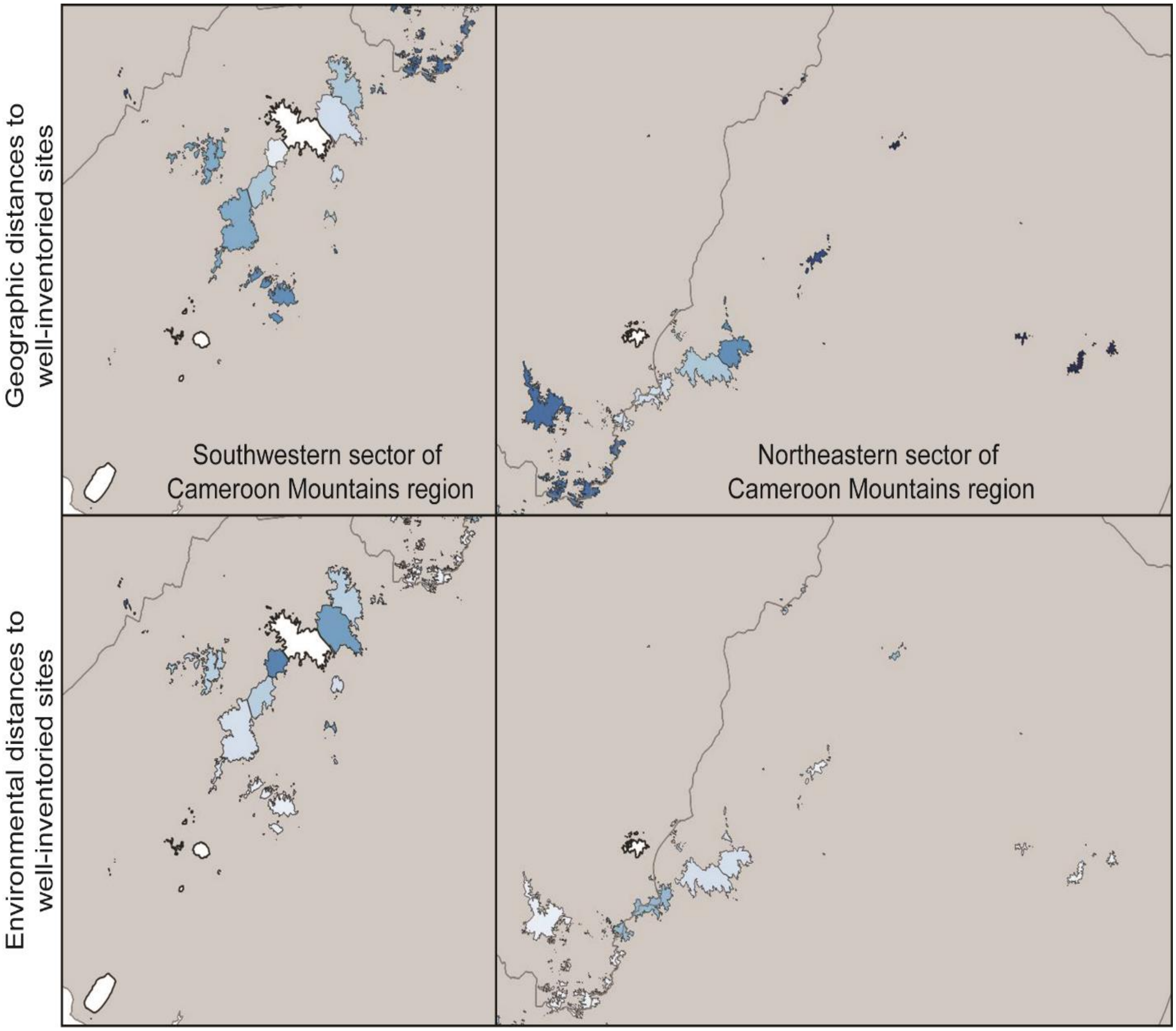

Figure 2.4. Summary of gaps in coverage in terms of inventories of plants in the Cameroon Mountains region. White indicates well-known sites; darker shades of blue indicate greater distance (geographic space) or difference (environmental space) from well-surveyed sites. Left-hand column is the southwestern part of the chain; right-hand column is the northeastern part of the chain.

Table 2.1. Highland areas in the continental portion of the Cameroon Mountains region with focus in Cameroon

Montane Unit	Number of species sampled	Latitude	Longitude	Elevation (m)	Degree of documentation
Mandara Mountains	518	10.4942	13.6359	1079	2
Benue National Park	309	8.0405	14.0066	851	2
Faro Reserve	17	7.7151	12.4251	1021	1
Tchabal Gandaba	155	7.0911	14.4376	1013	2
Tchabal Mbabo	215	7.2406	12.1458	2166	2
Ngel Nyaki Mountain forest	0	7.0903	11.0667	1167	0
Mambila Plateau	213	7.3838	11.7303	1140	3
Rhum Rocks	0	6.4671	11.0387	1603	0
Ijim and mt. Oku forest block	920	6.1146	10.2856	2200	2
Kumbo area	1	6.2032	10.6848	1650	1
Kagwene	70	6.2717	9.4338	1025	1
Bali & Bafut Ngemba Forest Reserve	415	5.8291	10.1026	1615	2
Mt. Bamboutos and Lebialem highlands	222	5.6008	10.0400	2176	2
Mt. Lefo	95	5.8641	10.3453	1239	2
Santchou forest reserve	134	5.2602	10.0472	801	2
Bakossi National Park	2412	5.0169	9.8454	2171	3
Mt Mwaneangumba	2412	4.9969	9.8564	2040	3
Rumpi hills	326	4.8886	9.2418	1749	1
Mt. Nlonako	351	4.9031	9.9578	1606	1
Mt. Kupe	10	4.7921	9.6779	966	1
Mt. Cameroon	2435	4.2833	9.2167	2600	3

CHAPTER THREE

CHARACTERISATION OF VEGETATION, FLORISTIC COMPOSITION, AND STRUCTURE IN TROPICAL MONTANE FOREST IN THE RUMPI HILLS FOREST RESERVE, CAMEROON

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Preface

This chapter addresses in a broad view the vegetation patterns of the Rumpi Hills Forest Reseve. It analyses the vegetation, floristic composition and structure.

ABSTRACT

The Rumpi Hills Forest Reserve (RHFR) is a Montane forest area located in southwestern Cameroon. Although it is thought to hold rich biodiversity and diversed vegetation types, few studies have been undertaken to characterise its floristic composition and vegetation patterns. The study characterised vegetation patterns in the reserve with a view to understanding how elevation influences species' distributions and diversity. Also the study intended to provide the first detailed plant species inventory in this important tropical rainforest in Southwestern Cameroon. The floristic composition and vegetation patterns of the reserve were studied in 25 1-ha plots spread along an elevational gradient. In each plot trees and lianas of diameter at breast height (dbh) ≥10 cm were measured, and shrubs <10 cm were measured in nested plots of 10 x 10 m. Lianas with dbh ≥1 cm were measured with the help of a caliper and diameter tape. They were measured above the last roots that get into the canopy. In all, 16,761 trees, shrubs and lianas with dbh ≥1 cm were census, representing 71 families, 279 genera, and 617 morphospecies. Floristic composition ranged between 94 - 132 species with a mean of 117.5 species ha^{-1} in lowland forest (50-200 m), to 36 - 41 species with a mean of 38.5 species ha^{-1} in montane cloud forest (1600-1778 m) near the summit of Mount Rata. Two-way Indicator Species Analysis (TWINSPAN) classified the 25 plots into six vegetation types: lowland evergreen rainforest, lowland evergreen rainforest on basalt rocks, mid-elevation evergreen forest, submontane forest, transitional submontane forest, and montane cloud forest. Detrended correspondence analysis (DCA) highlighted the importance of elevation in shaping vegetation patterns, with a strong positive relationship to species turnover. Results of this study revealed that the different vegetation types in the RHFR show impressive variation in terms of structure, species composition, diversity, and spatial distribution. Furthermore, the fine-scale inventory data of species obtained in this study could be useful in developing predictive models for efficient management of tropical rainforests.

Key words: Floristic composition, Vegetation patterns, Montane forest, Rumpi Hills, Cameroon Mountains

3.1 INTRODUCTION

Floristic composition, forest structure and vegetation characterisation have been treated widely in tropical forest ecosystems (Campbell et al., 2006; Lutz et al., 2012; Noumi, 2013; Neelo et al., 2015; Zhong et al., 2015), with such importance that they need to be obtained for tropical forest zones that are less studied. One such area is the tropical montane forest along the continental part of the Cameroon Volcanic Line (Ayonghe et al., 1999; Marzoli et al., 2000, Sainge et al., 2017),where relatively few studies have assessed forest structure and composition along elevational gradients using permanent sampling plots (Sunderland et al., 2003;

Tchouto, 2004; Gonmadje at el., 2011; Sainge, 2016), as opposed to the more common general plant collection assessments (e.g., Thomas, 1996; Thomas, 1997; Cheek et al., 2000; Kenfack, 2001; Cheek et al., 2004; Harvey et al., 2004; Harvey et al., 2010). Some studies have examined changes in species composition and diversity across environmental and geographic gradients (Gentry, 1988; Imani et al., 2017) but vegetation structure and composition are also influenced strongly by elevation (Richter, 2008; Imani et al., 2017). Vegetation systems at different elevations on different substrates in montane ecosystems differ in biomass production, carbon storage, and biodiversity conservation value (Richter, 2008). Globally, the concepts of elevational gradients along tropical mountain ranges have been treated (Vallèrié, 1971; Thomas, 1984; Hemp, 2002; Desalegn and Beierkuhnlein 2003; Lovett et al., 2006; Fischer et al., 2011; Rutten et al., 2015). Still, this subject remains little-study in the Cameroon Mountains.

The study of elevational gradients in different mountain systems in the tropics began as far back as 1800, with the work of Alexander von Humboldt and Charles Darwin. This early work led many scientists to center research on these questions (Fischer et al., 2011), aiming to understand distributional changes of species along different mountain gradients (Hemp, 2002; Lovett et al., 2006, Rutten et al., 2015). In east Africa, the work of Lovett et al., (2006), Rutten et al., (2015), and Desalegn and Beierkuhnlein, (2003) outlined basic patterns, and classified and delimited the montane forest as starting at 700-1000 m elevation.

The Rumpi Hills Forest Reserve (RHFR) covers much of an important patch of wet montane forest in the continental part of the Cameroon Mountains that is considered a critical site for biodiversity conservation (Oates et al., 2004; Birdlife International, 2016). White, (1983) classified the RHFR as part of the Guineo-Congolian region of endemism, and Barthlott et al., (2005) placed it under the Mount Cameroon sub-center of endemism. Despite its high diversity potential, RHFR has received little attention in terms of detailed botanical and ecological surveys, when compared to surrounding mountain masses, such as Mt Nta Ali (Achoundong, 1995; Thomas, 1996), Mt Kupe (Cheek et al., 2004; Tchiengué, 2004), Bakossi National Park and Mt Mwanenguba (Cheek et al., 2004; Tchiengué, 2004; Tchouto and Ebwekoh, 1999), Mt Nlonako (Kenfack, 2001), Mount Etinde (Thomas and Cheek, 1992; Tchouto, 1995), Mt Oku (Tame and Asonganyi, 1995; Maisels and Forboseh, 1997; Maisels et al., 2000; Cheek et al., 2000), Mt Cameroon (Cable and Cheek, 1998; Tchouto et al., 1999), and Tchabal Mbabo (Thomas and Thomas, 1996; Chapman et al., 2004). Understanding the Rumpi Hills ecosystem in detail will thus allow detailed comparisons across the region in the future, as well as identification of crucial conservation elements represented there.

A few brief botanical collections were made in the Rumpi Hills area between 1976 and 1984, with a total of 57 botanical specimens collected by D. Dang, R. Letouzey, S. Polhill, B. Satabie, and D. Thomas (National Herbarium of Cameroon database). It was not until 1996 that Thomas (1996) did a more intensive, rapid botanical survey of the area. Later, during 2000-2004, botanical reconnaissance trips were made by D. Thomas, D. Kenfack, and M. Sainge, during which 68 specimens were collected and deposited at the Missouri Botanical Garden Herbarium and the National Herbarium of Cameroon. The RHFR and surrounding areas are threatened by encroachment from both small farm estates and large-scale agro-industrial companies (Kupsch et al., 2014).

In this study, we aimed to characterise vegetation patterns across RHFR, and to present a first detailed assessment of its vegetation structure and composition. We sought to assemble an understanding of the flora of the region. The specific objectives of this study were thus to understand composition, structure, classification and patterns in the RHFR along an elevational gradient.

3.2 MATERIALS AND METHODS

3.2.1 Study area

The RHFR lies near the southwestern extreme of the Cameroon Mountain range. It is located in Ndian Division, South West Region, Cameroon, and stretches across latitudes 4.6-5.0°N and longitudes 8.8-9.4°E, with an elevational range of 50-1778 m. It covers an area of 458.2 km^2 (Forestry Ordinance 51 1941). Data were collected in clusters of 1-ha sampling plots: southern plots (numbers 1-8) were located on level terrain at elevations of 50-200 m; northern plots (numbers 18-25) were located on fairly level terrain at elevations of 400-600 m; four plots (numbers 14 -17) were on basaltic rocks at elevations of 250-300 m; and eastern plots (numbers 9-13) were on undulating terrain at elevations of 1200-1778 m. Plots were sampled based on accessibility and availability of funds (Figure 3.1).

The climate of the RHFR is typical of that of equatorial Cameroon, being hot and humid, with two distinct seasons: dry (December to March) and wet (April to November). An annual average rainfall of 5000 mm has been reported for the reserve (Nembot and Tchanou, 1998). Temperature fluctuates with elevation, with coldest temperatures at the top of Mt Rata; although no climate station is located in this area, Nembot and Tchanou, (1998) reported a mean temperature of 22˚C for the reserve. This reserve forms a topographic platform for different river sources that supply the Chad, Benue, Sanaga, Congo, and Manyu Rivers (Ngwa, 1978). Rivers originating in this reserve flow in five directions: north into Lake Chad via the Logone River;

northwest via the Benue River, the Kimbi River, and the Katsina Ala River; southwest into the Gulf of Guinea via the Ndian (Moriba), Moko, Meme, Mungo, and Wouri rivers; southeast via the Kadei River, a tributary of the Congo River; and west into Nigeria via the Munaya and Mbo rivers.

3.2.2 Field sampling

A reconnaissance survey based on topographic and vegetation maps of the reserve (Letouzey, 1985) was carried out to identify homogeneous areas of putatively different vegetation types (Sainge and Cooper, 2014). Data collection was done from February to June 2015, using line transects. Each transect (plot) measured 500 m long x 20 m wide, and was subdivided into 25 quadrats of 20 x 20 m to ease data collection and to reduce error margins. All 625 quadrat in the entired 25 hectare permanent plots were sampled (Condit 1998, Thomas et al., 2003, Sunderland et al., 2003). For each plot, GPS coordinates were recorded for the four corners, including start and end points, via careful, repeated measures to assure accuracy. In each plot, all trees, and lianas with diameter at breast height (dbh, 1.3 m above ground) ≥10 cm were identified, measured with a diameter tape, tagged, recorded, and mapped using their GPS coordinates. Small trees, shrubs, and lianas with dbh <10 cm were sampled and measured with calipers in 10 x 10 m quadrats located in every fifth 20 x 20 m quadrat in each 1 ha plot. Plots were all permanent with permanent poles and GPS coordinates of the four corners recorded (Condit, 1998, Thomas et al., 2003). The forest was divided into 4 vertical strata: trees <10 cm dbh as understory, 10-30 cm dbh as mid-canopy, 30-60 cm dbh as canopy and ≥60 cm dbh as emergent species. This was to have an idea on the degree of regeneration of the forest. This was more accurate than the height because dbh were measured using standard dbh tapes and calipers whereas height was based on estimate. Plots were set based on accessibility to sample different vegetation types and elevations (Figure 3.1). To assess the sampling effort of our study, a sampling intensity of 0.006% was carried out (Branthomme, 2004). Finally, we recorded non-plot-based, observational data (general plant collection) to detect and include species not recorded in the standardised plots.

3.2.3 Taxonomy and plant identification

In the field, plant identification was done using five-letter codes, including the first three letters of the genus and the first two letters of the species. In cases where the genus and species were not known or only the genus or family was known, arbitrary codes were generated to represent morphospecies. For unknown species (those that could not be identified, partly identified, or with doubtful identification), herbarium specimens were collected. These specimens were labeled, pressed, dried, sorted, and classified for proper identification at the National Herbarium of Cameroon, in Yaoundé (YA). Flowers and fruits were collected when the species was possibly new to science, endangered, or endemic to the area. In the field two Botanists (Sainge Moses and Mambo Peter) were responsible for all plant identification, and in the herbarium, Sainge Moses and Mezili Paul carried out detailed identification of all specimens. Identification in the herbarium was accomplished by comparing and matching specimens with existing collections and available floras and monographs (Hutchinson and Dalziel, 1954, 1958, 1963; Vivien and Faure, 1985; Keay, 1989; Thomas et al., 2003; Cheek et al., 2004; Harvey et al., 2004; Harvey et al., 2010; Onana, 2011, 2013). Plant classification followed species lists in the Angiosperm Phylogeny Group (APG III, 2009), with the Papilionaceae, Caesalpiniaceae and Mimosaceae merged into Fabaceae, and Sterculaceae, Tiliaceae, and Malvaceae merged into Malvaceae (Judd et al., 1999; APG III, 2009).

3.2.4 Data analysis

Regression analysis was used to assess relationships between numbers of species and elevation, in PAST, version 2.17 (Hammer et al., 2001). Individuals not identified to the species level (1271 individuals with dbh ≥10 cm, 10.6%) and singletons (57 individuals, 0.5%) were excluded from the inventory completeness calculations. Thus, 10,709 fully identified individual trees (dbh ≥10 cm, 88.9%) of 311 species were used in the analysis. Classification of the vegetation was achieved using two-way indicator species analysis (TWINSPAN; Hill, 1979). Detrended Correspondence Analysis (DCA or DECORANA; Hill and Gauch 1980) was used to examine relationships between vegetation types and elevation, via PC-ORD for Windows, version 5.10 (McCune and Mefford, 2006). Forest structure and composition were described using basal area, relative density, relative basal area, relative frequency, and importance value index (Dallmeier, 1992). Inventory completeness was assessed using EstimateS version 9.1.0 (Colwell, 2013: http://purl.oclc.org/estimates), via the Chao2 estimator of expected species richness (S_{exp}), which is calculated from the number of species actually known (S_{obs}), and frequency of detection of rare species; completeness was calculated as:

$$Inventory\ completeness = \frac{S_{obs}}{S_{exp.}}$$

3.3 RESULTS

3.3.1 Species accumulation curve and inventory completeness

Inventory completeness varied considerably among plots, from a low of 0.36 in lowland plot 2 to 1.0 in lowland plot 1, with an overall mean of 0.73. Most of the plots had completeness values in the range of 0.60-0.81, resulting in a strong positive relationship between estimated and observed species across the Rumpi Hills Forest Reserve, with an inventory completeness of about 80%.(Figure 2A, B, and C)

3.3.2 Composition and Floristic Structure

In lowland evergreen rainforest, 4086 individual trees were recorded, while we recorded 3600 in mid-elevation evergreen forest, 1831 in lowland evergreen rainforest on basalt rocks, 1191 in submontane forest, 1066 in montane cloud forest, and 263 in transitional forest. For all vascular plants ≥10 cm, mean number of trees per hectare were not the same across vegetation types: 596 in submontane forest (range 542-649), 533 in montane cloud forest (range 518-548), 511 in lowland evergreen rainforest (range 397-559), 458 in lowland evergreen rainforest on basalt rocks (range 423-480), 450 in mid-elevation evergreen forest (range 376-531), and 263 in transitional forest (263) (Table 3.1). The mean number of shrubs/0.05 ha varied as follows: 180 shrubs/0.05 ha in lowland evergreen rainforest (range 140-212), 146 in lowland evergreen forest on basalt rocks (124-155), to 71 in montane cloud forest (59-83). The mean number of lianas ranged from 6 lianas per hectare (range 0-12) in lowland evergreen rainforest, 5 in mid-elevation evergreen forest (0-11), to no lianas in montane or transitional forest at dbh ≥10 cm.

Mean basal area ranged from 37.5 m^2 per hectare in lowland evergreen rainforest (range 28.4-44.2 m^2 ha^{-1}), to 34.4 m^2 ha^{-1} in montane cloud forest (34.3-34.5) (Table 1), for trees ≥10 cm dbh. For shrubs <10 cm dbh, mean basal areas were low, ranging from 0.27 in lowland evergreen rainforest (range 0.11-0.98 m^2/0.05 ha), to 0.09 m^2 ha^{-1} in montane cloud forest (0.06-0.12 m^2 ha^{-1}). Lianas ≥10 cm dbh ranged from basal areas of 0.11 m^2 ha^{-1} in lowland evergreen rainforest to 0.01 m^2 ha^{-1} in submontane forest.

Species composition by family for trees ≥10 cm dbh was Fabaceae (954 individuals of 58 species), Rubiaceae (310 individuals of 35 species), Annonaceae (422 individuals of 26 species), and Sapotaceae (385 individuals) and Malvaceae (381 individuals) with 19 species each. Importance in terms of family (importance value index) for the most common 15 families was highest in Lecythidaceae (39.8), Fabaceae (20.9), Phyllanthaceae (19.9), and Malvaceae (13.7), and lowest in Sapotaceae (6.3), Ebenaceae (5.3), Sapindaceae (4.7), and Melastomataceae (1.8). The most broadly distributed family was Fabaceae, occurring in 390 of 625 quadrats sampled, whereas the rarest families in terms of number of species and abundance were Dilleniaceae, Malpighiaceae, Erythroxylaceae, and Lepidobotryaceae, each represented by a single individual of a single species.

Lower-elevation vegetation types held many more species than highest-elevation vegetation types. The linear multivariate model reveals a strong significant negative relationship between species richness and elevation ($r^2 = 0.783$ $P = 0.005$; Figure 5), with numbers declining from 117.5 species (94-132 species) in lowland rainforest to 38.5 species (36-41 species) at highest-elevation sites (Table 1). In all, 16,761 individuals of trees, shrubs, and woody lianas were recorded in 25 1-ha plots across the RHFR; casual observational data provided records of an additional 254 individual plants in 62 families, 129 genera, and 210 species. Indeed, 132 species were recorded only outside of the standardized sampling plots and quadrats. A total of 109 individuals in 21 morphospecies (97 trees/shrubs, and 12 lianas) could not be identified to species level, and 21 individuals could not be identified even to family. The most common 15 families accounted for 62% of total individual abundance across all plots.

Species composition changed drastically between vegetation types, as only a few species occurred in all vegetation types: *Bridelia grandis* (Phyllanthaceae), *Cola verticillata* (Malvaceae), *Sapium ellipticum* (Euphorbiaceae), and *Symphonia globulifera* (Clusiaceae). At the other end of the spectrum, many species were recorded only in single vegetation types, such as *Afrostyrax kamerunensis*, *Afzelia bipindensis, A. pachyloba, Alexis cf. cauliflora, Allanblackia gabonensis*, and *Allophylus megaphyllus* in lowland forest; *Beilschmiedia gabonensis*, *Leptonychia lasiogyne*, *Maesa kamerunensis*, *M. lanceolata*, *Syzygium staudtii*, and *Tricalysia amplexicaulis* in submontane forest; *Alangium chinense*, *Alchornea floribunda*, and *Elaeophorbia drupifera* in transitional submontane forest; and *Acridocarpus macrocalyx* and *Allophylus grandifolius* in mid-elevation evergreen forest.

3.3.3 Multivariate analysis

Classification

The 25 1-ha plots were classified in the TWINSPAN analysis into six groups at 50% similarity (Figure 3.3). Plots 1-8 corresponded to lowland evergreen forest (sensu Letouzey 1968, 1985), characterized by an abundance of *Oubanguia alata* (556 individual trees). Plots 14-17 grouped together, corresponding to lowland evergreen forest on basalt rocks that was abundant in *Crateranthus talbotii* (103 individual trees). Plots 18-25 clustered together, and can be termed mid-elevation forest, abundantin *Strombosia grandifolia* (324 individual trees) and *Leonadoxa africana* (192 individual trees). Plots 9-10 were in submontane forest abundant in *Tabernaemontana ventricosa* (102 individual trees), *Cola verticilata* (75 individual trees), and *Dasylepis thomasii* (68 individual trees). Plots 11-12 were in montane cloud forest abundant in *Strombosia* sp. (146 individual trees), *Carapa oreophila* (125 individuals), and *Xylopia africana* (121 individual trees). Lastly, plot 13 was in transitional submontane forest rich in *Macaranga* sp. (56 individual trees), *Trema orientalis* (46 individual trees), *Bridelia grandis* (33 individual trees), and *Pauridiantha viridiflora* (31 individual trees).

Ordination

The floristic dataset of 25 plots was also subjected to DCA analysis and plotted along axes 1 and 2. Variation was expressed along axis 1 with an eigenvalue of 0.772 and a gradient length of 4.183, which reflects high variation among vegetation types and species composition. Vegetation types 4, 5, and 6 (submontane, montane, and transitional forest, respectively) separated toward the positive side of DCA axis 1, whereas vegetation types 1, 2, and 3 (lowland, basalt, and mid-elevation respectively) separated toward the negative end (Figure 3.4). DCA axis 2 showed a weaker eigenvalue of 0.478, with a gradient length of 2.389 (Table 3.2). Figure 3.4 shows patterns suggesting that vegetation types 1-3 are more closely related than vegetation 4-6.

A high species-environment correlation for axis 1 indicates a strong association between vegetation types and elevation (Table 3.3), which can be verified from the biplot record (Table 3.4). A Monte Carlo permutation test (998 runs) with an eigenvalue of axis 1 and significant at $P < 0.001$ confirmed the strong relationship between species composition and elevation (Table 3.4).

3.3.4 Vegetation patterns

3.3.4.1 Lowland evergreen rainforest rich in *Oubanguia alata*

This vegetation type occurs along the southern edge of RHFR, mainly at elevations below 250 m. The vegetation is intact, evergreen, and continuous from the ground layer of herbaceous plants in dense undergrowth to emergent tree species. The canopy is more or less continuous, with only a few emergents. In all, 4086 trees were recorded, belonging to 51 families, 174 genera, and 291 species. Seven species were not fully identified, and 2 individuals were not identified either to family, genus or species. Shrubs with dbh <10 cm totaled 1065 individual trees in 44 families, 126 genera, and 208 species. Only one individual of this group of plants was not identified to genus or species. Lianas of <10 cm dbh included 7 individuals in 3 species, 2 genera, and 2 families.

Dominant tree families in lowland evergreen rainforest were Fabaceae (61 species), Annonaceae (26 species), and Euphorbiaceae, Malvaceae, and Phyllanthaceae, with 19 species each. Frequent genera included *Cola* (14 species), *Diospyros* (13 species), and *Drypetes* and *Trichoscypha* (10 species each). Our TWINSPAN analysis presented *Oubanguia alata* (556 individuals or 13.6% of total individuals in this vegetation type), *Protomegabaria stapfiana* (263 individuals, 6.4%), and *Korupodendron songweanum* (164 individuals, 4%), as dominant species in this vegetation type.

Some emergent and upper canopy species were 30-55 m tall, with huge buttresses that spanned 3-10 m on the forest floor, and trunk diameters of up to 2.5 m. Such tree species included *Microberlinia bisulcata*, *Irvingia gabonensis*, *Desbordesia glaucescens*, *Pycnanthus angolensis*, *Saccoglottis gabonensis*, *Omphalocarpum* cf *elatum*, and *Engomegoma gordonii*. The canopy, 20-35 m tall, was composed of tree species such as *Tetraberlinia bifoliolata*, *Korupodendron songweanum*, *Santiria balsamifera*, *Eriocoelum macrocarpum*, and *Pellegriniodendron diphyllum*.

The midstory was made up of small trees, mostly immature emergent and canopy trees, of approximately 10 m tall, composed of *Uvariopsis bakeriana*, *Craterispermum aristatum*, *Napoleonaea talbotii*, *Deinbollia angustifolia*, *Phyllobotryon spathulathum*, and *Gaertnera bieleri*. The ground layer, composed of herbaceous species, seedlings of the above layers, lianas, and creepers, was dominated by *Deinbollia angustifolia Impatiens niamniamensis*, *Costus afer*, *Anubias barteri*, *Begonia quadrialata*, and *Palisota hirsuta*. Seven large woody liana species were recorded in this forest type, of which *Connarus staudtii*, *Dichapetalum affine*, *Rhaphiostylis beninensis*, *Strychnos tricalysioides*, and *Santalinoides afzelii* were most common.

3.3.4.2 Lowland evergreen rainforest on basalt rocks rich in *Crateranthus talbotii*

This vegetation type occurs along the western edge of the RHFR, at elevations of 250-300 m, and dominated by *Crateranthus talbotii* (103 individuals, 5.6%), *Trichilia prieureana* (65 individuals, 3.5%), and *Anthonotha macrophylla* (64 individuals, 3.4%). This vegetation type is characterised by trees, shrubs, and lianas with dbh <22 cm, and is made up of patches of huge basalt rocks. In all, 1831 trees with dbh ≥10 cm were recorded in this vegetation type, in 39 families, 122 genera, and 175 species. Two tree species could not be identified to genus. Shrubs with dbh <10 cm amounted to 40 families, 85 genera, and 119 species. This forest type was characterised by a rich diversity of Fabaceae (234 individuals of 21 species), Rubiaceae (29 individuals of 11 species), Phyllanthaceae (98 individuals of 10 species), and Anacardiaceae (72 individuals of 10 species).

3.3.4.3 Mid-elevation evergreen forest rich in *Strombosia grandifolia*

This vegetation type occurs in the northern parts of RHFR, at elevations of 300-800 m, and is dominated by *Strombosia grandifolia* (324 individuals) and *Leonadoxa africana* (192 individuals). We sampled 3600 trees in 42 families, 119 genera, and 176 species, and 1153 shrubs in 41 families, 98 genera, and 150 species. Most frequent shrub genera were *Strombosia, Leonodoxa, Trichilia*, and *Tabernaemontana*; the most common species were *Strombosia grandifolia*, *Oubanguia alata*, *Trichilia prieureana*, *Tabernaemontana brachyantha*, and *Mammea africana*.

3.3.4.4 Submontane forest rich in *Tabernaemontana ventricosa*

This forest type was found along the eastern edge of RHFR at 800-1600 m elevation. It occurs close to the villages of Dikome Balue, Madie, and Iyombo, and along the western edge of the reserve around Mbange, Bossunga, Boa Yenge, and Motindi village. RHFR submontane forest occurs on steep cliffs and inaccessible slopes. We sampled 1191 trees of 38 families, 75 genera, and 98 species; shrubs totaled 240 individuals in 32 families, 49 genera, and 60 species. This forest type was rich in Rubiaceae (9 species), Euphorbiaceae (7 species), and Meliaceae (6 species) for trees; common species included *Tabernaemontana ventricosa*, *Dasylepis thomasii*, *Cola verticillata*, *Diospyros cinnabarina*., and *Garcinia conrauana* . The submontane forest forms part of a mosaic of forest and grassland savanna above 1300-1600 m.

The canopy here is relatively short (20-25 m tall), with only a few tall trees, such as *Cylicomorpha solmsii*, *Eriocoelum macrocarpum*, *Guarea cedrata*, and *Sapium ellipticum*, reaching 30-35 m tall. Two species of large woody lianas were recorded: *Dichapetalum heudelotii*, and *Salacia pyriformis*.

3.3.4.5 Transitional submontane forest rich in *Trema orientalis*

This vegetation type is a mosaic of forest and grassland occurring along the eastern edge of RHFR at 1300-1600 m, close to Dikome Balue and is characterized by low diversity. We sampled 263 individual trees in 20 families, 31 genera, and 32 species with dbh ≥10 cm, and 61 individual trees in 16 families, 22 genera, and 24 species with dbh <10 cm. Dominant tree families with dbh ≥10 cm were Euphorbiaceae and Rubiaceae (4 species each); all other families were represented by only 1-2 tree species. Dominant genera were *Macaranga*, *Trema*, *Pauridiantha*, *Bridelia*, and *Margaritaria*; most common species included *Macaranga* sp., *Trema orientalis*, *Pauridiantha viridiflora*. Rare species recorded here included *Thunbergia affinis, Alangium chinense*, *Trichoscypha preussii*, *Monodora myristica*, and *Uvariastrum pynaertii*.

3.3.4.6 Montane cloud forest rich in *Carapa oreophila*

Montane forest is found on the eastern edge of RHFR, at elevations above 1600 m, up to the summit of Mount Rata (~1778 m). We sampled 1066 individual trees with dbh ≥10 cm, in 25 families, 38 genera, and 48 species, and 146 individual trees with dbh <10 cm in 19 families, 24 genera, and 31 species. This forest was characterised by species of Rubiaceae (6 species), Clusiaceae (5 species), and Salicaceae (4 species). Most abundant species included *Strombosia* sp. (146 individuals, 13.7%), *Carapa oreophila* (125 individuals, 11.7%), *Xylopia africana* (121 individuals, 11.4%), and *Dasylepis thomasii* (91 individuals, 8.5%). The upper canopy layer was 20-25 m tall, with most species covered with numerous species of epiphytes (orchids, mosses, lichens, liverworts, bryophytes, and Piperaceae). Understory vegetation was sparse. Woody lianas were scarce, with only two species recorded (*Dichapetalum rudatisii*, and an unknown species).

3.4 DISCUSSION

The diverse and heterogeneous vegetation structure and composition in RHFR are likely related to the complex physical features, elevational differences (from 50 m to the top of Mount Rata at 1778 m), and climatic factors, such as the southwest monsoonal (warm wet) winds that are weak in the dry season and strong in the wet season (Ngwa, 1978; Neba, 1999). Rainfall is highest in the southwestern corner of the reserve; however, to date, no weather station has been installed to provide detailed climatic data for the reserve. We assume that, given its proximity to Korup National Park, with an average yearly rainfall of ~5 m (Newbery and Gartlan 1996; Chuyong et al., 2000; Thomas et al., 2003; Chuyong et al., 2004), RHFR also has high rainfall. Temperature within the reserve is variable, with temperatures lowest at the top of Mount Rata.

The reserve per se is free from human settlements, as no villages are located within its core area. However, 12 villages are within 1-3 km of the reserve margins: Matamani in the northwest; Mata in the north; Madie and Dikome Balue in the east; Munyange and Nalende in the south; Mbange, Bossunga, Motindi, Lipenja Mukete in the west; and Meka and Besingi in the northwest. The above parameters (i.e., the enclaved nature of RHFR, its importance as a watershed, and lack of human settlements) are indicators of conservation importance. This importance is emphasized by our findings of high tree, liana, and shrub diversity (Table 3.1), and the large number of species of high conservation priority and the fact that it occurs in a recognized biodiversity hotspot (White, 1983; Myers et al., 2000; Barthlott et al., 2005; Onana, 2013; Marchese, 2015).

The sampling intensity of 0.006% is actually low compared to the standard for management inventory procedure for Cameroon 0.5-2.5% with a sampling unit of one hectare (Branthomme, 2004).

3.4.1 Vegetation Patterns and Floristic Composition

Multivariate analyses (TWINSPAN and DCA) classified RHFR vegetation into six types. Letouzey, (1985) recognized seven vegetation types in RHFR: the Atlantic Biafran forest; Atlantic littoral forest, (which in the current study is classified as lowland forest); piedmont forest; degraded submontane forest; submontane forest; highly degraded evergreen forest, (which was not sampled in the present study); and submontane grassland (also not sampled), as well as various combinations of fallow, grazed, and human-inhabited areas (Figure 3.1).

The RHFR is part of the chain of mountains of Cameroon and Nigeria that includes the Cameroon Mountains and associated highland biomes (Burgess et al., 2007; Cronin et al., 2014). It forms part of the Lower Guinea Forest, with high levels of species richness and endemism (Barthlott et al., 2005; Plumptre et al., 2007; Burgess et al., 2007). The occurrence of a mosaic of forest and grassland on the upper slopes of Mount Rata, at elevations of 1300-1600 m, is not surprising, as grassland savanna begins at 1500 m in the Takamanda Forest Reserve, in the South West Region of Cameroon (Sunderland et al., 2003), and above 2000 m on Mount Cameroon (Richards, 1963). Administratively, Mount Rata falls outside of the RHFR; and represents the highest peak in the Rumpi Hills range.

Our results differ from patterns in lowland forest at other sites, like Takamanda Forest Reserve (South West Region, Cameroon) where lowland forest is dominated by Huaceae (*Afrostyrax kamerunensis*) and Irvingiaceae (*Irvingia*, *Klainedoxa*, *Desbordosea*) (Sunderland et al., 2003). However, the RHFR lowland forest showed the same dominance trends as the lowland forest in nearby Korup National Park (Thomas et al., 2003).

Forest structure changed from lowland evergreen forest (50-200 m), with huge, emergent trees 35-55 m tall, to montane cloud forest (1778 m), with a lower and more even canopy 20-25 m tall, comprising tree with branches covered by Piperaceae, Orchidaceae, ferns, liverworts, lichens, etc. Our results agree with Letouzey, (1985) that RHFR is composed of different vegetation types, and show that these vegetation types demonstrate impressive variation in structure, species composition, and distribution. Furthermore, RHFR contains a distinct montane vegetation type, as defined by the TWINSPAN analysis, at elevations above 1600 m. This result concurs with Vallèrié, (1971) and Thomas, (1984), who both classified upper montane forest as starting from 1600 m in the Cameroon Mountains region.

3.4.2 Elevation

The effect of elevation on the vegetation of the RHFR was pronounced, as it influences vegetation pattern, vegetation structure, species diversity and species composition of the area (Figure 3.3) across an elevational range of 50-1778 m. We documented marked changes in species composition with elevation: lowland evergreen rainforest on basalt and lowland evergreen rainforest rich in *O. alata* were relatively richer in species than the other vegetation types. The inverse relationship between species richness and elevation recorded in RHFR was consistent with results obtained in many studies (Hamilton, 1975; Henrik et al., 2006; Chuyong et al., 2011). Dauby et al., (2013) investigated tree diversity patterns in communities of evergreen forest trees in five landscapes of western Gabon, and concluded that mean alpha and gamma diversities were much higher in the hilly region, with differences in elevation explained a significant part of species turnover. The decrease of alpha diversity with elevation within the hilly region could be associated with mass effects, which are expected to enrich valley and slopes (Dauby et al., 2013). Overall, in RHFR lowland forest is characterized by large trees with huge buttresses and lianas (Tchouto, 2004, Ewango, 2010). At high elevations, shrubs and tree branches are covered with bryophytes and vascular epiphytes, and tree boles and leaves are covered by moss and liverworts, with a minimal liana population.

Our detailed sampling across vegetation types and elevations within and near the RHFR makes our data useful both for ecological understanding and for guiding management decisions. Given that our plots are permanent, with GPS-based outlines of each sampling plot (http://hdl.handle.net/1808/25180), the opportunity arises to repeat these censuses in the future (e.g., every 5-10 years) to understand the dynamics of the forest (Condit, 1998). Such detailed monitoring would allow a far more nuanced understanding of the status and condition of these forests, as well as of the effects of global change on their composition and structure.

3.4.3 Conservation Implications

Conservation prioritisation usually takes in consideration a number of factors for designing conservation areas, including species composition, structure, vegetation patterns, and socioeconomic and cultural importance of the sites. Our study confirmed that the RHFR is a rich site in terms of vegetation; analysis of species composition segregated the community into six vegetation types, some of which are found outside of the administrative boundaries of the reserve (e.g., Mt Rata). Our records of rare species, such as *Deinbollia* *angustifolia*, *Korupodendron songweanum*, *Gambeya korupensis*, and *Oubanguia alata*, in lowland forest; *Crateranthus talbotii* in lowland basalt forest; *Rhaptopetalum geophylax* and *Cylicomorphia solmsii* in submontane forest; and *Carapa oreophila*, *Oncoba lophocarpa*, and *Xylopia africana* in montane forest may upgrade the conservation interest in the Rumpi Hills forest area. Particular species occured only in specific vegetation types, or in a few adjacent types. Hence protection of the different vegetation types including Mt Rata is paramount for conservation prioritisation.

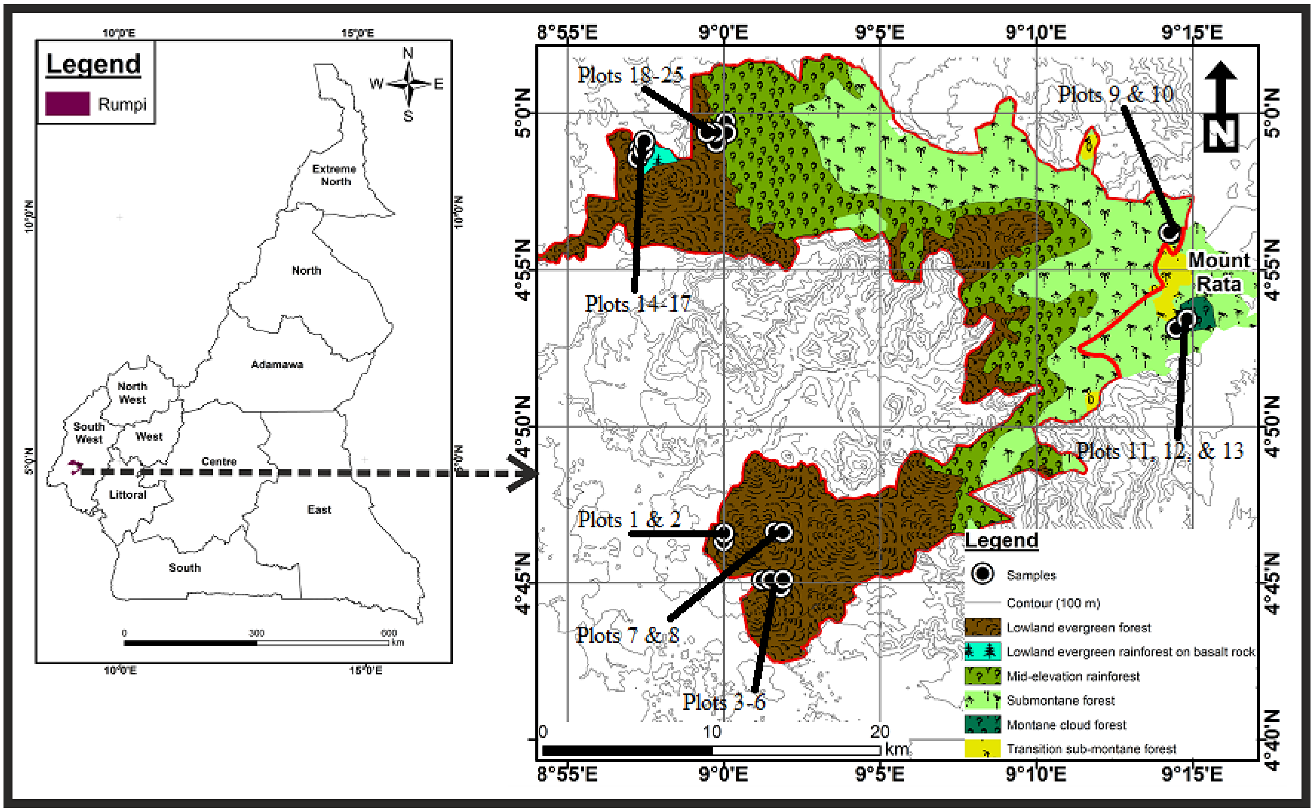
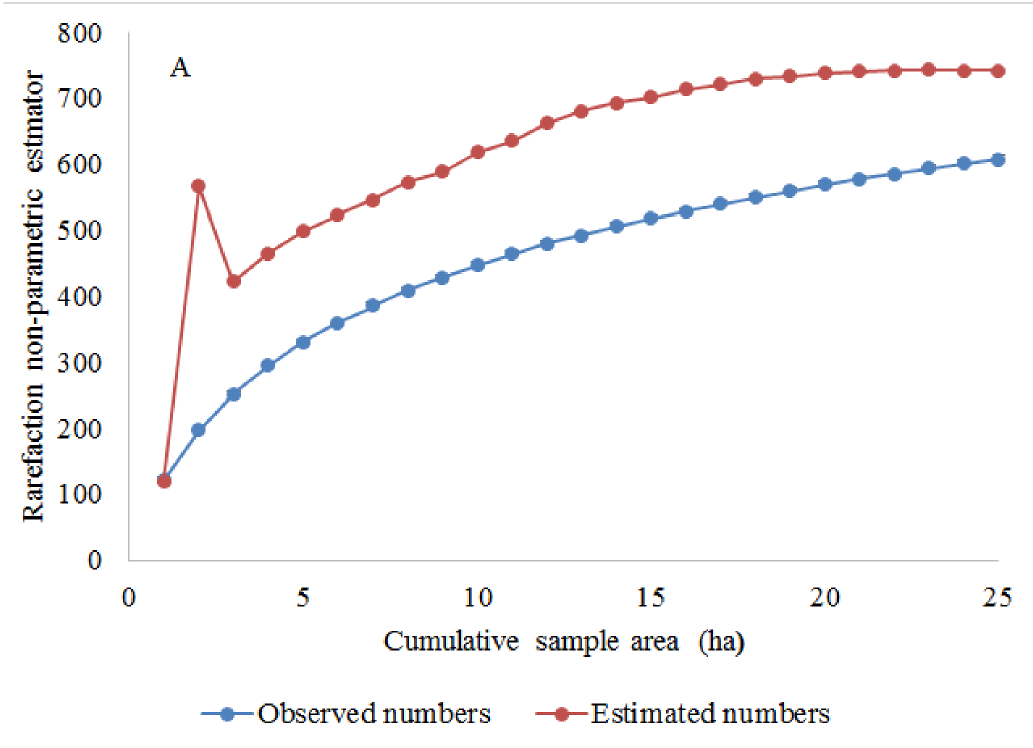
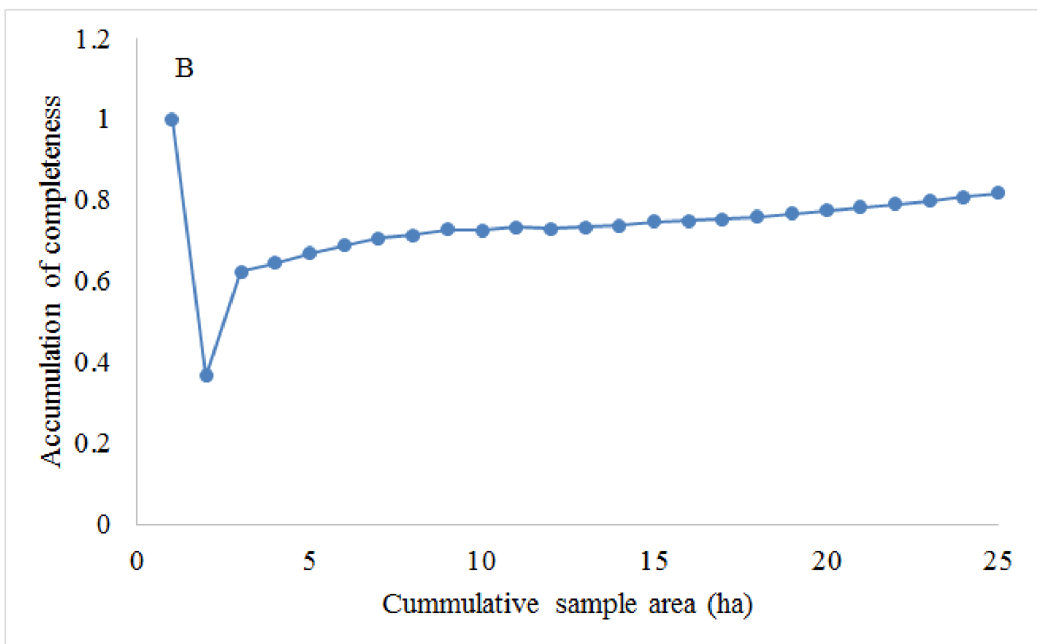


Figure 3.1 Permanent sampling plot locations in different vegetation types across Rumpi Hills Forest Reserve, Cameroon.


A
Rarefaction non-parametric estimator
Cumulative sample area (ha)
0
100
200
300
400
500
600
700
800
0
5
10
15
20
25
Observed numbers
Estimated numbers


B
Accumulation of completeness
Cummulative sample area (ha)
0
0.2
0.4
0.6
0.8
1
1.2
0
5
10
15
20
25

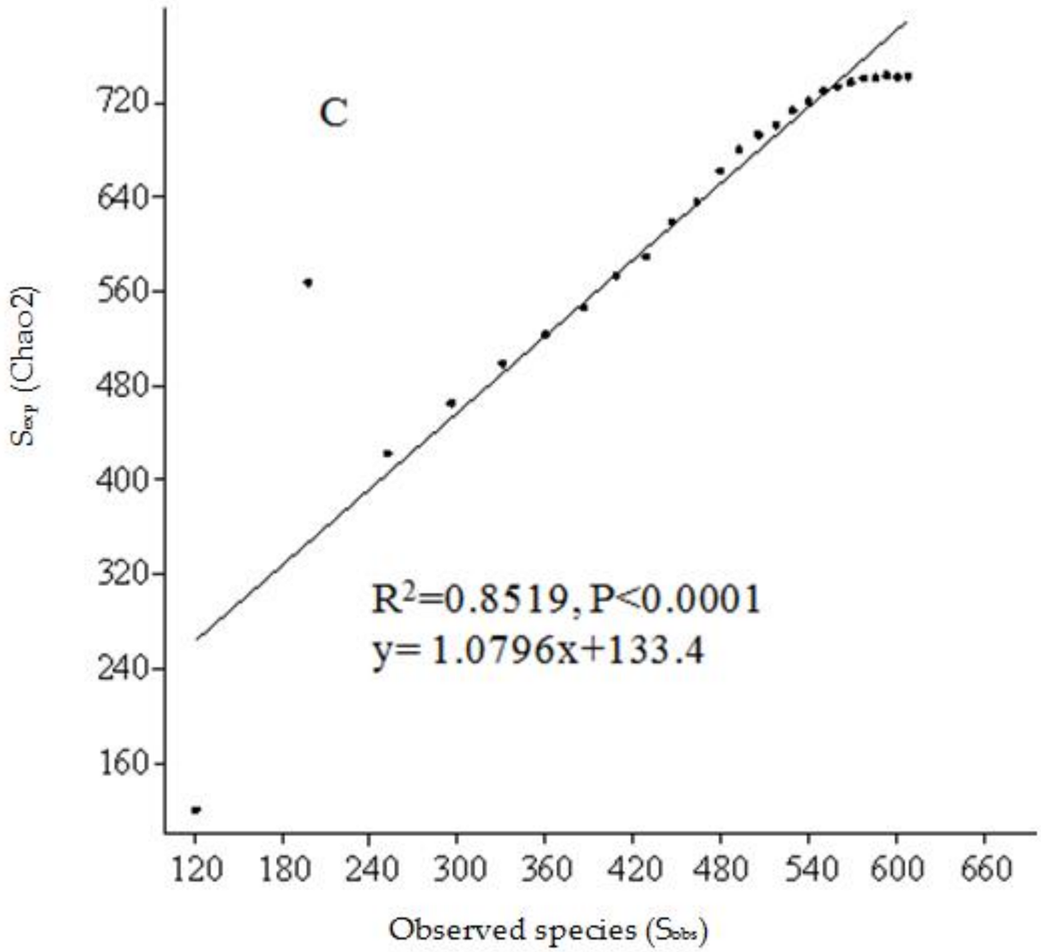


Figure 3.2 (A) Species area curve for observed species richness (S_{obs}), and estimated species richness (S_{exp}), (B) inventory completeness for observed species richness (S_{obs}) and (C) a strong linear relationship between estimated and observed species in the Rumpi Hills Forest Reserve, Cameroon

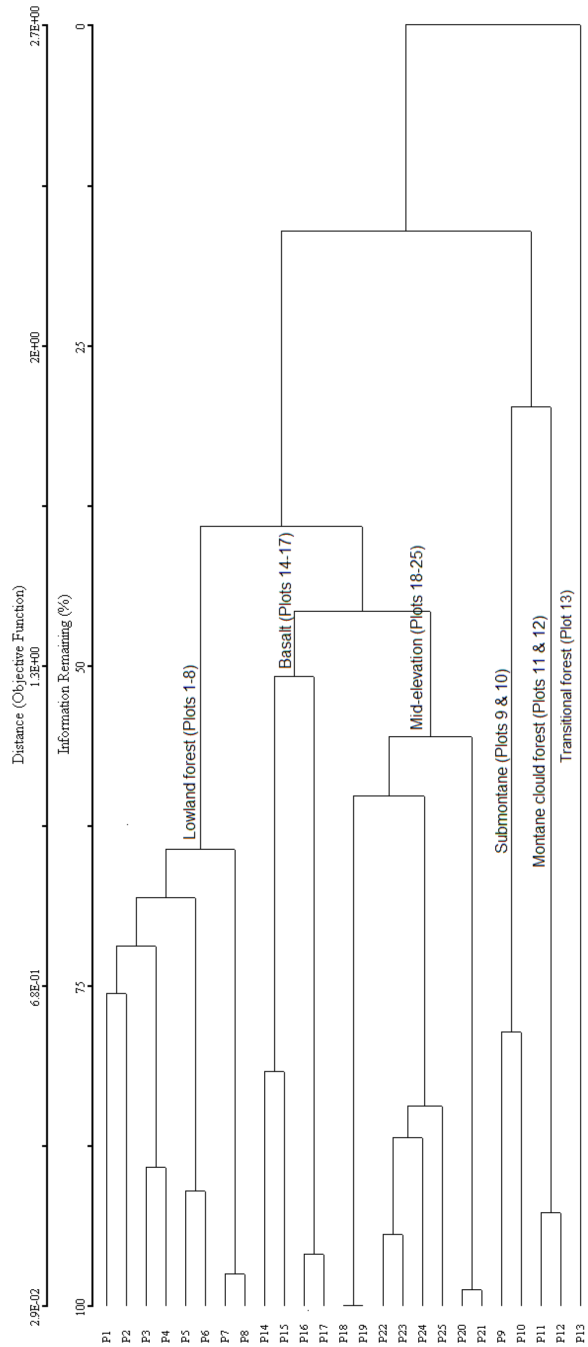


Figure 3.3 TWINSPAN dendrogram of 311 species of vascular plants with dbh ≥10 cm in 25 1-ha plots in the Rumpi Hills Forest Reserve, Cameroon.

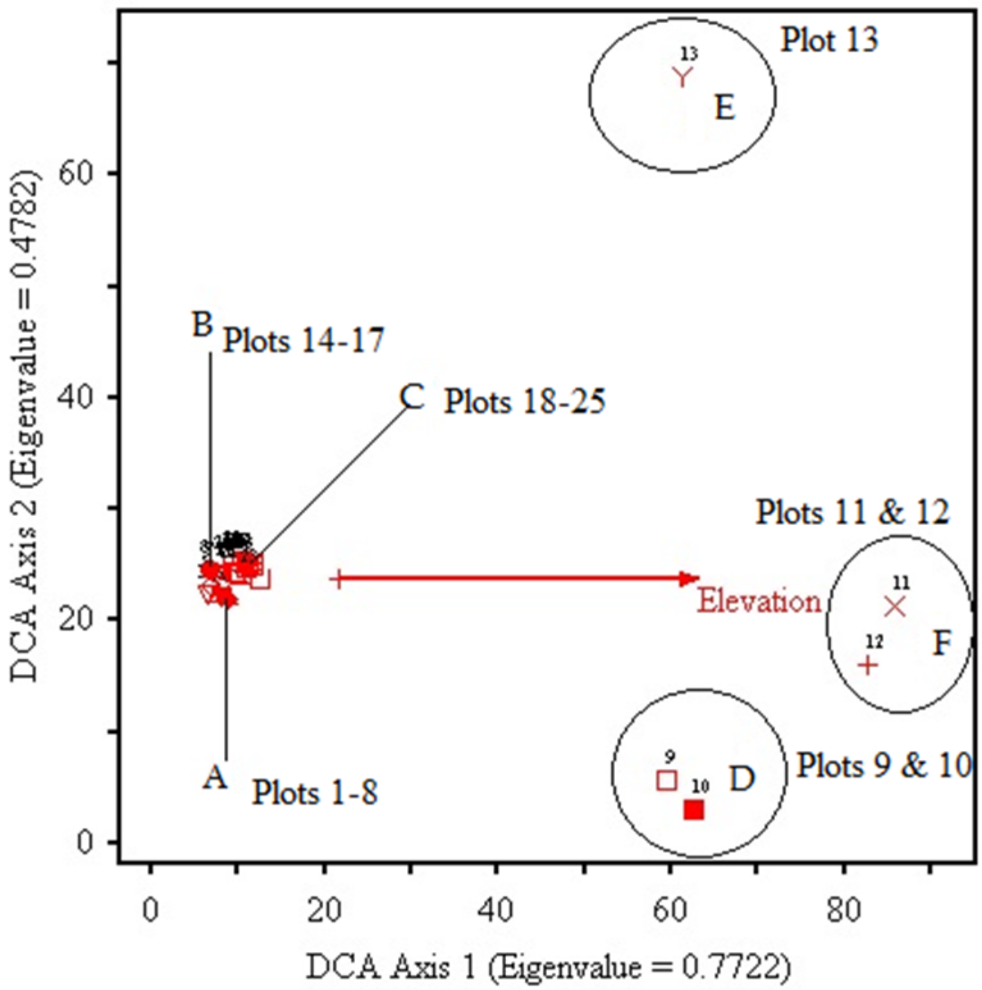


Figure 3.4 Floristic Detrended Correspondance Analysis (DCA) with 25 plots and six vegetation type from TWINSPAN analysis tree species data following field sampling of the Rumpi Hills Forest Reserve, Cameroon

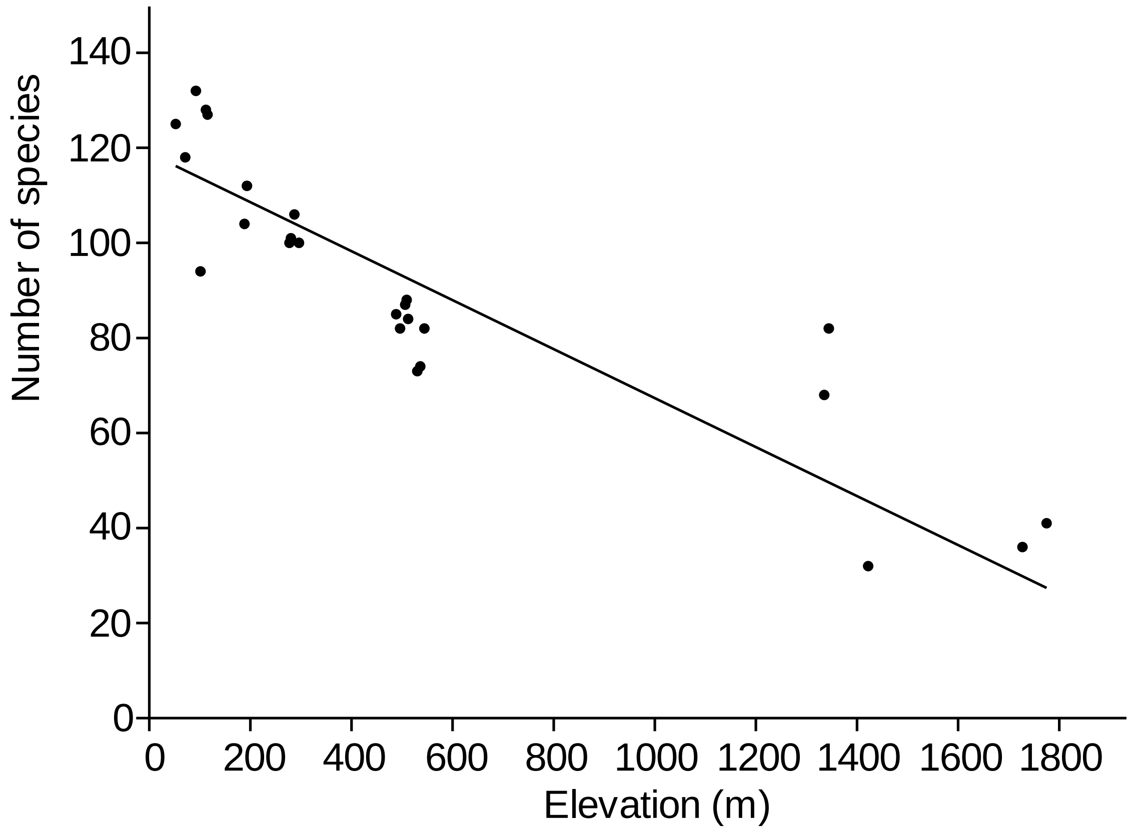


Figure 3.5 Association between elevation and numbers of species of trees of dbh ≥10 cm recorded in 25 1-ha plots in the Rumpi Hills Forest Reserve, Cameroon. The relationship has a slope of 78.3%, which is significantly different from a slope of zero ($P < 0.05$).

Table 3.1 Summary of number of hectares sampled, mean number of species, mean tree density, and mean basal area of trees ≥10 cm dbh recorded in each vegetation type in the Rumpi Hills Forest Reserve, Cameroon.

Vegetation type	No of ha	Mean # species	Mean # tree density/ha	Mean BA/ha
Lowland evergreen rainforest	8	117.5 (94-132)	510.75 (397-559)	37.49 (28.4-44.2)
Lowland evergreen rainforest on basalt rocks	4	102.75 (100-106)	457.75 (423-480)	30.8 (26.79-35)
Mid-elevation rainforest	8	81.875 (73-88)	450 (376-531)	26.94 (20.94-32.36)
Submontane forest	2	75 (68-82)	595.5 (542-649)	33.27 (32.4-34.13)
Transitional submontane Forest	1	32 (32)	263 (263)	15.93 (15.93)
Montane cloud forest	2	38.5 (36-41)	533 (518-548)	34.41 (34.31-34.51)

Mean # species = Mean number of species, Mean # tree density/ha = Mean number of trees density/ha, Mean BA/ha = Mean Basal Area/ha

Table 3.2 Summary of Detrended Correspondence Analysis (DCA) of 25, 1-ha plots in the Rumpi Hills Forest Reserve, Cameroon

	Axis 1	Axis 2	Axis 3	Total inertia
DCA				3.7374
Eigenvalue	0.7722	0.4781	0.3069	
Length of gradient	4.181	2.389	2.423	
Inter-set correlation				
	Correlation			
Variance				
1. Elevation	0.986	0.00	0.00	

Table 3.3 Six vegetation types generated from TWINSPAN with vegetation code, vegetation types and elevational range in the Rumpi Hills Forest Reserve, Cameroon.

Vegetation code	Vegetation type	Elevation (m)
Lowland	Lowland evergreen rainforest abundant in *Oubanguia alata*.	50-250
Basalt	Lowland evergreen rainforest on basalt rocks abundant in *Crateranthus talbotii*	250-300
Mid-Elevation	Mid-elevation rainforest abundant in *Strombosia grandifolia*.	300-800
Submontane	Submontane forest rich in *Tabernaemontana ventricosa*	800-1600
Montane	Montane cloud forest abundant in *Carapa oreophila*	1600-1778
Transitional	Transitional submontane Forest abundant in *Trema orientalis*	1300-1450

Table 3.4 Monte Carlo test results showing eigenvalue, species elevational correlation, correlation and biplot scores obtained following field sampling of the Rumpi Hills Forest Reserve, Cameroon

		Randomized Data			
Real data		Monte Carlo test			
Axis	Eigenvalue	Mean	Minimum	Maximum	*P*
1	0.774	0.166	0.065	0.437	0.0010
2	0.676	0.803	0.690	0.823	
3	0.543	0.662	0.559	0.674	
Monte Carlo Test. species environmental correlation					
Real data		Randomized data			
Axis	spp-Envt corr.	mean	minimum	maximum	*P*
1	0.986	0.663	0.474	0.862	0.001
Correlation and biplot scores					
	Correlation			Biplot scores	
Variable	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2
1 Elevation	1.00	0.00	0.00	0.418	0.00

Table 3.5 Permanent sample plot locations in the Rumpi Hills Forest Reserve, Cameroon

Plot	Vegetation type	Location	Latitude (N)	Longitude (E)	Elevation (m)
1	Lowland	Munyange	4.77215	8.99985	101
2	Lowland	Munyange	4.77216	9.00021	92
3	Lowland	Munyange	4.75155	9.02040	52
4	Lowland	Munyange	4.75123	9.02041	71
5	Lowland	Munyange	4.74761	9.03051	115
6	Lowland	Munyange	4.74753	9.03096	112
7	Lowland	Munyange	4.77739	9.02708	188
8	Lowland	Munyange	4.77698	9.02704	193
9	Submontane	Madie River	4.93624	9.23804	1344
10	Submontane	Madie River	4.93629	9.23756	1335
11	Montane	Mt Rata	4.88627	9.24261	1775
12	Montane	Mt Rata	4.88492	9.24065	1727
13	Transitional Submontane	Mt Rata	4.89046	9.24694	1422
14	Basalt	Matamani	4.98074	8.95476	287
15	Basalt	Matamani	4.98082	8.95439	277
16	Basalt	Matamani	4.98046	8.95698	280
17	Basalt	Matamani	4.98035	8.95739	296
18	Mid-Elevation	Matamani	4.99087	9.00035	544
19	Mid-Elevation	Matamani	4.99092	9.00071	530
20	Mid-Elevation	Matamani	4.98980	9.00169	506
21	Mid-Elevation	Matamani	4.98948	9.00170	509
22	Mid-Elevation	Matamani	4.98868	8.99630	488
23	Mid-Elevation	Matamani	4.98864	8.99590	496
24	Mid-Elevation	Matamani	4.98956	8.99532	512
25	Mid-Elevation	Matamani	4.98980	8.99527	536

Appendix 3.1. Species occurrence in the different forest types in the Rumpi Hills Forest Reserve, Cameroon

Family	Species
Acanthaceae	*Thunbergia affinis*
Achariaceae	*Dasylepis thomasii* Obama & Breteler
Achariaceae	*Scottellia klaineana* Pierre
Alangiaceae	*Alangium chinense* (Lour.) Harms
Anacardiaceae	*Antrocaryon micraster* A.chev. & Guillaum.
Anacardiaceae	*Antrocaryon* sp.
Anacardiaceae	*Lannea welwitschii* (Hiern) Engl.
Anacardiaceae	*Pseudospondias microcarpa* (A.Rich.) Engl.
Anacardiaceae	*Sorindeia grandifolia* Engl.
Anacardiaceae	*Sorindeia juglandifolia* (A.Rich.) Planch.ex Oliv.
Anacardiaceae	*Trichoscypha acuminata* Engl.
Anacardiaceae	*Trichoscypha oliveri* Engl.
Anacardiaceae	*Trichoscypha klainei*
Anacardiaceae	*Trichoscypha patens* (Oliv.) Engl.
Anacardiaceae	*Trichoscypha preussii* Engl.
Anacardiaceae	*Trichoscypha* sp.10
Anacardiaceae	*Trichoscypha* sp.12
Anacardiaceae	*Trichoscypha* sp.22
Anacardiaceae	*Trichoscypha* sp.31
Anacardiaceae	*Trichoscypha* sp.4
Anacardiaceae	*Trichoscypha* sp.6
Anacardiaceae	*Trichoscypha* sp.72
Anacardiaceae	*Trichoscypha* sp.9
Anacardiaceae	*Trichoscypha* sp.I
Anisophylleaceae	*Anisophyllea meniaudii* Aubr. & Pelleg.
Anisophylleaceae	*Anisophyllea polyneura* Floret
Anisophylleaceae	*Anisophyllea purpurascens* Hutch. & Dalziel
Anisophylleaceae	*Anisophyllea sororia* Pierre
Anisophylleaceae	*Poga oleosa* Pierre
Annonaceae	*Annickia chlorantha* (Oliv.) Setten & P.J. Maas

Annonaceae	*Cleistopholis patens* (Benth.) Engl. & Diels
Annonaceae	*Cleistopholis staudtii* Engl. & Diels
Annonaceae	*Hexalobus* sp.
Annonaceae	*Isolona campanulata* Engl. & Diels
Annonaceae	*Isolona thonneri* (De Wild & Th. Dur.) Engl. & Diels
Annonaceae	*Monodora brevipes* Benth.
Annonaceae	*Monodora myristica* (Gaertn.) Dunal
Annonaceae	*Pachypodanthium staudtii* Engl. & Diels
Annonaceae	*Piptostigma oyemense* Pellegrin
Annonaceae	*Piptostigma pilosum* Oliv.
Annonaceae	*Piptostigma* sp.
Annonaceae	*Polyanthia suaveolens* (Engl. & Diels) Verdc
Annonaceae	*Polyceratocarpus parviflorus* (Baker f.) Ghesq.
Annonaceae	*Uvariastrum pynaertii* De Wild.
Annonaceae	*Uvariodendron connivens* (Benth.) R.E. Fr.
Annonaceae	*Uvariodendron giganteum* (Engl.) R.E. Fr.
Annonaceae	*Uvariopsis bakeriana* (Hutch. & Diels) Robyns & Ghesq.
Annonaceae	*Uvariopsis korupensis* Gereau & Kenfack
Annonaceae	*Uvariopsis submontana* Kenfack, Gosline & Gereau
Annonaceae	*Xylopia acutiflora* (Dunal) A.Rich.
Annonaceae	*Xylopia aethiopica* (Dunal) A.Rich.
Annonaceae	*Xylopia africana* (Benth.) Oliv.
Annonaceae	*Xylopia hypolampra* Mildbr.
Annonaceae	*Xylopia* sp.3
Annonaceae	*Xylopia* sp.I
Annonaceae	*Xylopia staudtii* Engl. & Diels
Annonaceae	*Xylopia villosa* Chipp
Apocynaceae	*Alstonia boonei* De Wild
Apocynaceae	*Funtumia elastica* (Preuss) Stapf
Apocynaceae	*Hunteria umbellata* (K. Schum) Hallier f.
Apocynaceae	*Landolphia congolensis* (Stapf.) Pichon
Apocynaceae	*Landolphia dulcis* (Sabine) Pichon

Apocynaceae	*Landolphia landolphioides* (Hallier f.) A.Chev.
Apocynaceae	*Pleiocarpa bicarpellata* Stapf.
Apocynaceae	*Pleiocarpa rostrata* Benth.
Apocynaceae	*Pleiocarpa* sp.
Apocynaceae	*Rauvolfia caffra* Sond.
Apocynaceae	*Rauvolfia mannii* Stapf.
Apocynaceae	*Rauvolfia vomitoria* Afzel.
Apocynaceae	*Tabernaemontana brachyantha* Stapf.
Apocynaceae	*Tabernaemontana crassa* Benth.
Apocynaceae	*Tabernaemontana ventricosa* Hochst. ex A.DC.
Apocynaceae	*Tabernanthe iboga* Baill.
Apocynaceae	*Voacanga africana* Stapf.
Apocynaceae	*Voacanga psilocalyx* Pierre ex Stapf.
Araliaceae	*Polycias fulva* (Hiern) Harms
Araliaceae	*Schefflera abyssinica* (Hochst.ex. A.Rich.) Harms
Araliaceae	*Schefflera barteri* (Seem) Harms
Asteraceae	*Vernonia conferta* Benth.
Asteraceae	*Vernonia frondosa* Oliv. & Hiern
Bignoniaceae	*Allophylus grandifolius* (Baker) Radlk.
Bignoniaceae	*Kigelia africana* (Lam.) Benth.
Bombacaceae	*Bombax buenopozense* P. Beauv.
Bombacaceae	*Ceiba pentandra* (L.) Gaertn.
Boraginaceae	*Cordia* sp.
Burseraceae	*Canarium schweinfurthii* Engl.
Burseraceae	*Dacryodes edulis* (G. Don) H.J.Lam
Burseraceae	*Dacryodes klaineana* (Pierre) H.J.Lam
Burseraceae	*Santiria balsamifera* Oliv.
Caricaceae	*Cylicomorpha solmsii* (Urb.) Urb.
Cecropiaceae	*Musanga cecropioides* R.Br. ex Tedlie
Cecropiaceae	*Myrianthus arboreus* P. Beauv.
Cecropiaceae	*Myrianthus preussii* Engl.
Celastraceae	*Salacia loloensis* Loes

Celastraceae	*Salacia pyriformis* (Sabine) Steud.
Chrysobalanaceae	*Chrysobalanus icaco* L.
Chrysobalanaceae	*Dactyladenia pallescens* (Baill.) G.T. Prance & F. White
Chrysobalanaceae	*Dactyladenia staudtii* (Engl.) G.T.Prance & F.White
Chrysobalanaceae	*Magnistipula* aff. *cuneatifolia* Hauman
Chrysobalanaceae	*Magnistipula glaberrima* Engl.
Chrysobalanaceae	*Maranthes kerstingii* (Engl.) G.T.Prance
Chrysobalanaceae	*Parinari chrysophylla* Oliv.
Chrysobalanaceae	*Parinari excelsa* Sabine
Clusiaceae	*Allanblackia gabonensis* (Pellegr.) Bamps
Clusiaceae	*Endodesmia calophylloides* Benth.
Clusiaceae	*Garcinia* cf *polyantha*
Clusiaceae	*Garcinia conrauana* Engl.
Clusiaceae	*Garcinia gnetoides* Hutch. & Dalziel
Clusiaceae	*Garcinia kola* Heckel
Clusiaceae	*Garcinia mannii* Oliv.
Clusiaceae	*Garcinia polyantha*
Clusiaceae	*Garcinia* sp.
Clusiaceae	*Garcinia* sp.1
Clusiaceae	*Garcinia staudtii* Engl.
Clusiaceae	*Mammea africana* Sabine
Clusiaceae	*Pentadesma butryacea* Sabine
Clusiaceae	*Pentadesma grandifolia* Baker f.
Clusiaceae	*Symphonia globulifera* L.f.
Combretaceae	*Combretum* sp.
Combretaceae	*Strephonema pseudocola* A.Chev.
Combretaceae	*Terminalia ivorensis* A.Chev.
Combretaceae	*Terminalia superba* Engl. & Diels
Connaraceae	*Connarus* sp.
Connaraceae	*Connarus* sp.1
Connaraceae	*Connarus staudtii* Gilg.
Connaraceae	*Jollydora duparquetiana* (Baill.) Pierre

Connaraceae	*Santalinoides afzelii* R.Br.ex Planch.
Convolvulaceae	*Neuropeltis acuminata* (P.Beauv.) Benth.
Convolvulaceae	*Neuropeltis pseudovelutina* Lejoly & Lisowski
Convolvulaceae	*Neuropeltis velutina* Hallier f.
Dichapetalaceae	*Dichapetalum affine* (Planch.ex Benth.) Breteler
Dichapetalaceae	*Dichapetalum dewevrei* De Wild. & Th. Dur.
Dichapetalaceae	*Dichapetalum heudelotii* (Planch. ex Oliv.) Baill.
Dichapetalaceae	*Dichapetalum phyiotrica*
Dichapetalaceae	*Dichapetalum rudatisii* Engl.
Dichapetalaceae	*Dichapetalum tomentosum* Engl.
Dichapetalaceae	*Tapura africana* Oliv.
Dilleniaceae	*Tetracera potatoria* Afzel. Ex G.Don
Ebenaceae	*Diospyros bipindensis* Gürke
Ebenaceae	*Diospyros abyssinica* (Hiern) F. White
Ebenaceae	*Diospyros canaliculata* De Wild
Ebenaceae	*Diospyros cinnabarina* (Gürke) F. White
Ebenaceae	*Diospyros conocarpa* Gürke & K. Schum.
Ebenaceae	*Diospyros gabunensis* Gürke
Ebenaceae	*Diospyros gracilescens* Gürke
Ebenaceae	*Diospyros hoyleana* White
Ebenaceae	*Diospyros iturensis* (Gürke) Letouzey & F. White
Ebenaceae	*Diospyros kamerunensis* Gürke
Ebenaceae	*Diospyros korupensis* Gosline
Ebenaceae	*Diospyros obliquifolia* (Hiern ex Gürke) F. White
Ebenaceae	*Diospyros preussii* Gürke
Ebenaceae	*Diospyros* sp.
Ebenaceae	*Diospyros* sp.3
Ebenaceae	*Diospyros* sp.4
Ebenaceae	*Diospyros* sp.5
Ebenaceae	*Diospyros suaveolens* Gürke
Ebenaceae	*Diospyros zenkeri* (Gürke) F. White
Erythroxylaceae	*Erythroxylum mannii* Oliv.

Euphorbiaceae	*Alchornea floribunda*
Euphorbiaceae	*Croton sylvaticus* Hochst.
Euphorbiaceae	*Croton sylvaticus* Hochst.
Euphorbiaceae	*Crotonogyne preussii* Pax
Euphorbiaceae	*Dichostemma glaucescens* Pierre
Euphorbiaceae	*Discoclaoxylon hexandrum* (Mull.Arg.) Pax & K. Hoffm.
Euphorbiaceae	*Discoglypremna caloneura* (Pax) Prain
Euphorbiaceae	*Elaeophorbia drupifera* (Thonn.) Stapf.
Euphorbiaceae	*Euphorbia* sp.2
Euphorbiaceae	*Jatropha curcas* L. (Cult.)
Euphorbiaceae	*Klaineanthus gaboniae* Pierre ex Prain
Euphorbiaceae	*Macaranga monandra* Müll.Arg.
Euphorbiaceae	*Macaranga* sp.
Euphorbiaceae	*Macaranga spinosa* Müll.Arg.
Euphorbiaceae	*Mallotus oppositifolius* (Geiseler) Müll.Arg.var.oppositifolius
Euphorbiaceae	*Mareya micrantha* (Benth.) Müll.Arg.
Euphorbiaceae	*Mareyopsis longifolia* (Pax) Pax & K. Hoffm.
Euphorbiaceae	*Neoboutonia glabrescens* Prain
Euphorbiaceae	*Pycnocoma macrophylla* Benth.
Euphorbiaceae	*Ricinodendron heudelotii* (Baill.) Pierre ex Baill.
Euphorbiaceae	*Sapium ellipticum* (Krauss) Pax
Euphorbiaceae	*Tetrorchidium didymostemon* (Baill.) Pax & K.Hoffm.
Fabaceae	*Acacia pennata* Willd.
Fabaceae	*Afzelia bella* Harms
Fabaceae	*Afzelia bipindensis* Harms
Fabaceae	*Afzelia pachyloba* Harms
Fabaceae	*Albizia adianthifolia* (K. Schum.) W.F. Wright
Fabaceae	*Albizia ferruginea* Benth.
Fabaceae	*Albizia* sp.
Fabaceae	*Albizia* sp.4
Fabaceae	*Albizia zygia* (DC.) J.F. Macbr.
Fabaceae	*Amphimas ferrugineus* Pellegr.

Fabaceae	*Amphimas pterocarpoides*
Fabaceae	*Angylocalyx oligophyllus* (Baker) Baker f.
Fabaceae	*Anthonotha cladantha* (Harms)J.Léonard
Fabaceae	*Anthonotha fragrans* (Baker f.) Exell & Hillc.
Fabaceae	*Anthonotha lamprophylla* (Harms)J.Léonard
Fabaceae	*Anthonotha macrophylla* P. Beauv.
Fabaceae	*Aphanocalyx microphyllus* Harms
Fabaceae	*Baikiaea insignis* Benth.
Fabaceae	*Baphia buettneri* Harms
Fabaceae	*Baphia capparidifolia* Baker f.
Fabaceae	*Baphia laurifolia* Baill.
Fabaceae	*Baphia* sp.
Fabaceae	*Berlinia auriculata* Benth.
Fabaceae	*Berlinia bracteosa* Benth.
Fabaceae	*Berlinia hollandii* Benth.
Fabaceae	*Calpocalyx dinklagei* Harms
Fabaceae	*Calpocalyx heitzii* Pellegr.
Fabaceae	*Copaifera mildbraedii* Harms
Fabaceae	*Crudia* sp.
Fabaceae	*Cryptosepalum congolanum*
Fabaceae	*Dialium bipindense* Harms
Fabaceae	*Dialium dinklagei* Harms
Fabaceae	*Dialium pachyphyllum* Harms
Fabaceae	*Didelotia africana* Baill.
Fabaceae	*Didelotia morelii* Aubr.
Fabaceae	*Distemonanthus benthamianus* Baill.
Fabaceae	*Erythrina milbraedii* Harms
Fabaceae	*Erythrophleum ivorensis* A. Chev.
Fabaceae	*Eurypetalum unijugum* Harms
Fabaceae	*Gilbertiodendron demonstrans* (Baill.) J.Léonard
Fabaceae	*Gilbertiodendron dewevrei* (De Wild.) J. Léonard
Fabaceae	*Gilbertiodendron* sp.2

Fabaceae	*Hylodendron gabunense* Taub.
Fabaceae	*Hymenostegia korupensis* Wer.
Fabaceae	*Leonardoxa africana* (Baill.) Aubrév. Subsp. Rumpiensis
Fabaceae	*Leptoderris ledermannii* Harms
Fabaceae	*Microberlinia bisulcata* Aubr.
Fabaceae	*Milletia* sp.
Fabaceae	*Millettia hypolampra* Harms
Fabaceae	*Newtonia griffoniana* (Baill.) Baker f.
Fabaceae	*Parkia bicolor* A. Chev.
Fabaceae	*Parkia* sp.
Fabaceae	*Pellegriniodendron diphyllum* (Harms) J. Léonard
Fabaceae	*Pentaclethra macrophylla* Benth.
Fabaceae	*Piptadeniastrum africanum* (Hook.f.) Brenan
Fabaceae	*Plagiosiphon longitubus* (Harms) J.Léonard
Fabaceae	*Pterocarpus soyauxii* Taub.
Fabaceae	*Talbotiella korupensis* Mackinder & Wieringa
Fabaceae	*Tetraberlinia bifoliolata* (Harms Hauman
Fabaceae	*Tetraberlinia korupensis* Wieringa
Fabaceae	*Tetraberlinia polyphylla*
Fabaceae	*Tetrapleura tetraptera* (Schum. & Thonn.) Taub.
Fabaceae	*Zenkerella citrina* Taub.
Gentianaceae	*Anthocleista schweinfurthii* Gilg.
Gentianaceae	*Mostuea brunonis* Didr.
Hoplestigmataceae	*Hoplestigma klaineanum* Pierre
Huaceae	*Afrostyrax kamerunensis* Perkins & Gilg.
Huaceae	*Afrostyrax lepidophyllus* Mildbr.
Humiriaceae	*Saccoglottis gabonensis* (Baill.) Urban
Hypericaceae	*Harungana madagascariensis* Poir.
Icacinaceae	*Iodes africana* Welw. ex Oliv.
Icacinaceae	*Lasianthera africana* P. Beauv.
Icacinaceae	*Rhaphiostylis beninensis* (Hook.f.ex Planch.) Planch ex Bench.
Icacinaceae	*Rhaphiostylis viridiflora*

Irvingiaceae	*Desbordesia glaucescens* Van Tiegh.
Irvingiaceae	*Irvingia gabonensis* (Aubrey-Leconte ex O.Rorke) Baill.
Irvingiaceae	*Irvingia grandifolia* (Engl.) Engl.
Irvingiaceae	*Klainedoxa gabonensis* Pierre ex Engl.
Irvingiaceae	*Klainedoxa trillesii* Pierre ex van Tiegh.
Lamiaceae	*Vitex grandifolia* Gürke
Lamiaceae	*Vitex lehmbachii* Gürke
Lamiaceae	*Vitex oxycuspis* Baker f.
Lamiaceae	*Vitex* sp.2
Lamiaceae	*Vitex* sp.3
Lamiaceae	*Vitex* sp.4
Lamiaceae	*Vitex* sp.5
Lamiaceae	*Vitex* sp.I
Lauraceae	*Beilschmiedia acuta* Kostermans
Lauraceae	*Beilschmiedia gabonensis* (Meissn.) Benth. & hook.f.
Lauraceae	*Beilschmiedia mannii* (Meisn.) Benth. & Hook.f.
Lauraceae	*Beilschmiedia* sp.
Lauraceae	*Beilschmiedia* sp.2
Lauraceae	*Beilschmiedia* sp.22
Lauraceae	*Beilschmiedia* sp.6
Lauraceae	*Beilschmiedia talbotiae* (S. Moore) Robyns & Wilczeck
Lauraceae	*Hypodaphnis zenkeri* Stapf.
Lauraceae	*Persea americana* Mill. (Cult.)
Lecythidaceae	*Crateranthus talbotii* Baker f.
Lecythidaceae	*Napoleonaea* cf *heudelotii* A. Juss
Lecythidaceae	*Napoleonaea ergortonii* Baker f.
Lecythidaceae	*Napoleonaea talbotii* Baker f.
Lecythidaceae	*Oubanguia alata* Baker f.
Lecythidaceae	*Oubanguia laurifolia* (Pierre ex De Wild.) Tiegh.
Lecythidaceae	*Rhaptopetalum coriaceum* Oliv.
Lecythidaceae	*Rhaptopetalum depressum* Letouzey
Lecythidaceae	*Rhaptopetalum geophylax* Cheek & Gosline

Lecythidaceae	*Rhaptopetalum* sp.
Lecythidaceae	*Rhaptopetalum* sp.nov.
Lecythidaceae	*Scytopetalium klaineanum* Pierre ex Engl.
Leeaceae	*Leea guineensis* G. Don
Lepidobotryaceae	*Lepidobotrys staudtii* Engl.
Leptaulaceae	*Leptaulus daphnoides* Benth.
Leptaulaceae	*Leptaulus grandifolius* Engl.
Loganiaceae	*Strychnos angolensis* Gilg.
Loganiaceae	*Strychnos camptoneura* Gilg. & Busse
Loganiaceae	*Strychnos congolana* Gilg.
Loganiaceae	*Strychnos johnsonii* Hutch. & M.B. Moss
Loganiaceae	*Strychnos memecyloides* S.Moore
Loganiaceae	*Strychnos tricalysioides* Hutch. & M.B. Moss
Malpighiaceae	*Acridocarpus macrocalyx* Engl.
Malvaceae	*Cola altissima* Engl.
Malvaceae	*Cola* sp. nov.4
Malvaceae	*Cola cauliflora* Mast.
Malvaceae	*Cola chlamydantha* K. Schum.
Malvaceae	*Cola digitata*
Malvaceae	*Cola flaviflora* Engl. & K. Krause
Malvaceae	*Cola lateritia* K. Schum.
Malvaceae	*Cola lepidota* K. Schum.
Malvaceae	*Cola megalophylla* Brenan & Keay
Malvaceae	*Cola nitida* (Vent.) Schott & Endl.
Malvaceae	*Cola pachycarpa* K. Schum.
Malvaceae	*Cola rostrata* K. Schum.
Malvaceae	*Cola semecarpophylla* K. Schum.
Malvaceae	*Cola* sp.
Malvaceae	*Cola* sp.nov.
Malvaceae	*Cola* sp.nov.2
Malvaceae	*Cola* sp.nov.3
Malvaceae	*Cola suboppositifolia* Cheek & Kenfack

Malvaceae	*Cola verticillata* (Thonn.) Stapf ex A. Chev.
Malvaceae	*Duboscia viridifolia*
Malvaceae	*Glyphaea brevis* (Spreng) Monachino
Malvaceae	*Leptonychia echinocarpa* K. Schum
Malvaceae	*Leptonychia lasiogyne* K. Schum.
Malvaceae	*Leptonychia macrantha* (C.H. Wright) Burret
Malvaceae	*Microcos coriacea* (Mast.) Burret
Malvaceae	*Octolobus spectabilis* Welw.
Malvaceae	*Scaphopetalum blackii* Mast.
Malvaceae	*Sterculia tragacantha* Lindl.
Medusandraceae	*Soyauxia gabunensis* Baker f.
Medusandraceae	*Soyauxia* sp.1
Melastomataceae	*Memecylon afzelii* G.Don
Melastomataceae	*Memecylon calophyllum* Gilg.
Melastomataceae	*Memecylon candidum* Gilg.
Melastomataceae	*Memecylon englerianum* Cogn.
Melastomataceae	*Memecylon lateriflorum* (G. Don) Brem.
Melastomataceae	*Memecylon laurentii* De Wild
Melastomataceae	*Memecylon* sp.1
Melastomataceae	*Memecylon* sp.2
Melastomataceae	*Memecylon zenkeri* Gilg.
Melastomataceae	*Warneckea cinnamomoides* (G. Don) Jacq.-Fél.
Melastomataceae	*Warneckea jasminoides* (Gilg.) Jacq-Fél.
Melastomataceae	*Warneckea membranifolia* (Hook.f.) Jacq-Fél
Melastomataceae	*Warneckea pulcherrima* (Gilg.) Jacq-Fél.
Melastomataceae	*Warneckea* sp.I
Meliaceae	*Carapa angustifolia* Harms
Meliaceae	*Carapa dinklagei* Harms
Meliaceae	*Carapa oreophila* Kenfack
Meliaceae	*Carapa parviflora* Harms
Meliaceae	*Carapa zemagoana* Kenfack
Meliaceae	*Entandrophragma cylindricum* (Sprague) Sprague

Meliaceae	*Guarea cedrata* (A. Chev.) Pellegr.
Meliaceae	*Guarea glomerulata* Harms
Meliaceae	*Guarea* sp.
Meliaceae	*Guarea thompsonii* Sprague & Hutch.
Meliaceae	*Heckeldora staudtii* (Harms) Staner
Meliaceae	*Khaya ivorensis* A. Chev.
Meliaceae	*Trichilia* aff.*gilgiana* Harms
Meliaceae	*Trichilia prieureana* A. Juss
Meliaceae	*Turraeanthus africanus* (Welw.ex A.DC.) Pellegr.
Meliaceae	*Turraeanthus mannii* Baill.
Menispermaceae	*Penianthus camerounensis* A. Dekker
Menispermaceae	*Syrrhonema fasciculatum* Miers
Monimiaceae	*Glossocalyx brevipe*s Benth.
Moraceae	*Ficus mucuso* Welw. ex Ficalho
Moraceae	*Ficus* sp.
Moraceae	*Ficus* sp.3
Moraceae	*Ficus sur* Forssk.
Moraceae	*Milicia excelsa* (Welw.) C.C. Berg.
Moraceae	*Treculia africana* (Engl.) J. Léonard
Moraceae	*Treculia obovoidea* N.E.Br.
Myristicaceae	*Coelocaryon preussii* Warb.
Myristicaceae	*Pycnanthus angolensi*s (Welw.) Exell
Myristicaceae	*Scyphocephalium mannii* Warb.
Myristicaceae	*Staudtia gabunensis* Warb.
Myristicaceae	*Staudtia kamerunensis* Warb.
Myristicaceae	*Staudtia* sp.
Myrsinaceae	*Ardisia cymosa* Mez
Myrsinaceae	*Maesa kamerunensis* Mez
Myrsinaceae	*Maesa lanceolata* Forssk.
Myrtaceae	*Eugenia callophyloides* DC
Myrtaceae	*Eugenia* sp.2
Myrtaceae	*Eugenia talbotii* Keay

Myrtaceae	*Syzygium rowlandii* Sprague
Myrtaceae	*Syzygium staudtii* (Engl.) Mildbr.
Ochnaceae	*Campylospermum calanthum* (Gilg.) Farron
Ochnaceae	*Campylospermum elongathum*
Ochnaceae	*Campylospermum flavum*
Ochnaceae	*Campylospermum mannii*
Ochnaceae	*Lophira alata* Banks ex Gaertn.f.
Ochnaceae	*Rhabdophyllum affine* (Hook.f.) Tiegh.
Octoknemaceae	*Octoknema affinis* Pierre
Octoknemaceae	*Octoknema anuwiniencis*
Octoknemaceae	*Octoknema bakosiensis* Gosline & Malécot
Olacaceae	*Coula edulis* Baill.
Olacaceae	*Diogoa zenkeri* (Engl.) Exell & Mendonca
Olacaceae	*Engomegoma gordonii* Breteler
Olacaceae	*Heisteria parvifolia* Sm.
Olacaceae	*Olax triplinervia* Oliv.
Olacaceae	*Strombosia grandifolia* Hook.f.
Olacaceae	*Strombosia pustulata* Oliv.
Olacaceae	*Strombosia scheffleri* Engl.
Olacaceae	*Strombosia* sp.
Olacaceae	*Strombosia* sp.1
Olacaceae	*Strombosiopsis tetrandra* Engl.
Pandaceae	*Microdesmis puberula* Hook.f. ex Planch.
Pandaceae	*Panda oleosa* Pierre
Passifloraceae	*Barteria fistulosa* Mast
Phyllanthaceae	*Antidesma chevaleri*
Phyllanthaceae	*Antidesma laciniatum* Müll.Arg.
Phyllanthaceae	*Antidesma* sp.
Phyllanthaceae	*Antidesma vogelianum* Müll. Arg.
Phyllanthaceae	*Bridelia grandis* Pierre ex Hutch.
Phyllanthaceae	*Bridelia micrantha* (Hochst.) Baill.
Phyllanthaceae	*Cleistanthus letouzeyi* J. Leonard

Phyllanthaceae	*Keayodendron bridelioides* (Mildbr..ex Hutch. & Dalz.) Léandri
Phyllanthaceae	*Maesobotrya barteri* (Baill.) Hutch.
Phyllanthaceae	*Maesobotrya dusenii* (Pax) Hutch.
Phyllanthaceae	*Maesobotrya* sp.
Phyllanthaceae	*Maesobotrya staudtii* (Pax) Hutch.
Phyllanthaceae	*Margaritaria discoidea* (Baill.) Webster
Phyllanthaceae	*Protomegabaria stapfiana* (Beille) Hutch.
Phyllanthaceae	*Thecacoris batesii* Hutch.
Phyllanthaceae	*Thecacoris leptobotrya* (Müll.Arg.) Brenan
Phyllanthaceae	*Uapaca acuminata* (Hutch.) Pax & K. Hoffm.
Phyllanthaceae	*Uapaca guineensis* Müll.Arg.
Phyllanthaceae	*Uapaca staudtii* Pax
Polygalaceae	*Carpolobia lutea* G. Don
Putranjivaceae	*Drypetes aframensis* Hutch.
Putranjivaceae	*Drypetes afzelii* (Pax) Hutch.
Putranjivaceae	*Drypetes gossweileri* S. Moore
Putranjivaceae	*Drypetes ivorensis* Hutch. & Dalz.
Putranjivaceae	*Drypetes laciniata* (Pax) Hutch.
Putranjivaceae	*Drypetes molunduana* Pax & K.Hoffm.
Putranjivaceae	*Drypetes paxii* Hutch.
Putranjivaceae	*Drypetes* sp.3
Putranjivaceae	*Drypetes* sp.4
Putranjivaceae	*Drypetes* sp.6
Putranjivaceae	*Drypetes* sp.7
Putranjivaceae	*Sibangea similis* (Hutch.) Radcl.-Sm.
Rhamnaceae	*Maesopsis eminii* Engl.
Rhizophoraceae	*Cassipourea gummiflua* Tul.
Rhizophoraceae	*Cassipourea schizocalyx* C.H. Wright
Rubiaceae	*Aoranthe cladantha* (K. Schum) Somers
Rubiaceae	*Aulacocalyx caudata*
Rubiaceae	*Aulacocalyx jasminiflora* Hook.f.
Rubiaceae	*Aulacocalyx talbotii* (Wernham) Keay

Rubiaceae	*Belonophora coriacea*
Rubiaceae	*Belonophora wernhamii* Hutch. & Dalziel
Rubiaceae	*Bertiera laxa* Benth.
Rubiaceae	*Bertiera racemosa* (G. Don) K. Schum.
Rubiaceae	*Calycosiphonia spathicalyx* (K. Schum.) Robbr.
Rubiaceae	*Canthium* sp.
Rubiaceae	*Coffea* sp.
Rubiaceae	*Craterispermum aristatum* Wernham
Rubiaceae	*Cuviera subuliflora* Benth.
Rubiaceae	*Cuviera trilocularis* Hiern
Rubiaceae	*Euclinia longiflora* Salisb.
Rubiaceae	*Gaertnera bieleri* (De Wild) E.M.A. Petit
Rubiaceae	*Gaertnera* sp.
Rubiaceae	*Hallea ledermannii* (K.Krause) Verdc.
Rubiaceae	*Heinsia crinita* (Afzel.) G. Taylor
Rubiaceae	*Ixora bauchiensis* Hutch. & Dalziel
Rubiaceae	*Ixora guineensis* Benth.
Rubiaceae	*Ixora hippoperifera* Bremek
Rubiaceae	*Ixora nematopoda* K. Schum.
Rubiaceae	*Massularia acuminata* (G.Don) Bullock ex Hoyle
Rubiaceae	*Morelia senegalensis* A. Rich.
Rubiaceae	*Morinda lucida* Benth.
Rubiaceae	*Nauclea diderrichii* (De Wild.& T.Durand) Merrill
Rubiaceae	*Nauclea* sp.
Rubiaceae	*Oxyanthus laxiflorus* K.Schum.ex Hutch. & Dalziel
Rubiaceae	*Pauridiantha afzelii* (Hiern) Bremek.
Rubiaceae	*Pauridiantha floribunda* (K. Schum. & K.Krause) Bremek.
Rubiaceae	*Pauridiantha* sp.
Rubiaceae	*Pauridiantha viridiflora* (Schweinf. ex Hiern) Hepper
Rubiaceae	*Pausinystalia macroceras* (K. Schum.) Pierre ex Beille
Rubiaceae	*Pavetta baconiella* Bremek
Rubiaceae	*Pavetta staudtii* Hutch. & Dalziel

Rubiaceae	*Petitiocodon parviflorum* (Keay) Robbr.
Rubiaceae	*Petitiocodon* sp.
Rubiaceae	*Petitiocodon* sp.2
Rubiaceae	*Psilanthus mannii* Hook.f.
Rubiaceae	*Psychotria bimbiensis* Bridson & Cheek
Rubiaceae	*Psychotria brachyantha* Hiern
Rubiaceae	*Psychotria darwiniana* Cheek
Rubiaceae	*Psychotria dorotheae* Wernham
Rubiaceae	*Psychotria geophylax* Cheek & Sonké
Rubiaceae	*Psychotria peduncularis* (Salisb.) Steyerm
Rubiaceae	*Psychotria* sp.2
Rubiaceae	*Psychotria* sp.3
Rubiaceae	*Psychotria* sp.5
Rubiaceae	*Psychotria* sp.7
Rubiaceae	*Psychotria* sp.9
Rubiaceae	*Psydrax* sp.
Rubiaceae	*Rothmannia hispida* (K. Schum.) Fagerlind
Rubiaceae	*Rothmannia lujae* (De Wild.) Keay
Rubiaceae	*Rothmannia* sp.
Rubiaceae	*Schumanniophyton magnificum* (K. Schum.) Harms
Rubiaceae	*Stipularia africana* P. Beauv.
Rubiaceae	*Tarenna baconoides* Wernham var. baconoides
Rubiaceae	*Tarenna glandiflora* (Benth.) Hiern
Rubiaceae	*Tricalysia biafrana* Hiern
Rubiaceae	*Tricalysia coriacea* (Benth.) Hiern subs. c*oriacea*
Rubiaceae	*Tricalysia amplexicaulis* Robbr.
Rubiaceae	*Vangueriella chlorantha* (K. Schum.) Verdc.
Ruscaceae	*Dracaena arborea* (Wild.) Link
Ruscaceae	*Dracaena deisteliana* Engl.
Ruscaceae	*Dracaena talbotii* Rendle
Rutaceae	*Vepris adamaoua*
Rutaceae	*Vepris lecomteana* (Pierre) Cheek & T. Heller

Rutaceae	*Vepris soyauxii* (Engl.) Mziray
Rutaceae	*Vepris* sp.
Rutaceae	*Zanthoxylon gilletii* (De Wild.) P.G. Waterman
Rutaceae	*Zanthoxylon heitzii* Aubrév. Pellegr.
Rutaceae	*Zanthoxylon lemairei* (De Wild.) P.G. Waterman
Rutaceae	*Zanthoxylon* sp.2
Rutaceae	*Zanthoxylon* sp.I
Salicaceae	*Casearia barteri* Mast.
Salicaceae	*Homalium africanum* (Hook.f.) Benth
Salicaceae	*Homalium letestui* Pellegr.
Salicaceae	*Homalium longistylum* Mast.
Salicaceae	*Homalium macroptenum*
Salicaceae	*Homalium* sp.1
Salicaceae	*Oncoba glauca* (P.Beauv.) Planch.
Salicaceae	*Oncoba lophocarpa* Oliv.
Salicaceae	*Oncoba mannii* Oliv.
Salicaceae	*Oncoba ovalis* (Oliv.) Chipp
Salicaceae	*Oncoba* sp.
Salicaceae	*Phyllobotryon spathulathum* Müll.Arg.
Sapindaceae	*Allophylus africanus* P. Beauv.
Sapindaceae	*Allophylus grandifolius* (Baker) Radlk.
Sapindaceae	*Allophylus megaphyllus* Hutch. & Dalz.
Sapindaceae	*Allophylus* sp.
Sapindaceae	*Allophylus* sp.2
Sapindaceae	*Allophylus* sp.3
Sapindaceae	*Blighia sapida* Koenig
Sapindaceae	*Blighia welwitschii* (Hiern) Radlk.
Sapindaceae	*Chytranthus angustifolius* Exell
Sapindaceae	*Chytranthus edulis*
Sapindaceae	*Chytranthus* sp.
Sapindaceae	*Chytranthus talbotii* (Baker f.) Keay
Sapindaceae	*Deinbollia pycnophylla* Gilg ex Radlk.

Sapindaceae	*Deinbollia unijuga* D. W. Thomas
Sapindaceae	*Eriocoelum kerstingii* Gilg. ex Engl.
Sapindaceae	*Eriocoelum macrocarpum* Gilg. ex Radlk.
Sapindaceae	*Laccodiscus ferrugineus* (Baker) Radlk.
Sapindaceae	*Laccodiscus pseudostipularis* Radlk.
Sapindaceae	*Placodiscus* cf. *caudatus* Pierre ex Radlk
Sapindaceae	*Radlkofera calodendron* Gilg.
Sapotaceae	*Pradosia spinosa* Ewango & Breteler
Sapotaceae	*Englerophytum kennedyi*
Sapotaceae	*Englerophytum* sp.nov.
Sapotaceae	*Gambeya africanum* A.DC
Sapotaceae	*Gambeya boukokoensis* Aubbrév. & Pellegr.
Sapotaceae	*Gambeya delevoyi* De Wild.
Sapotaceae	*Gambeya korupensis* Ewango & Kenfack
Sapotaceae	*Gambeya lacourtianum* De Wild.
Sapotaceae	*Gambeya subnudum* Baker f.
Sapotaceae	*Lecomtedoxa klaineana* (Pierre & Engl.) Dubard
Sapotaceae	*Manilkara argentea*
Sapotaceae	*Manilkara lososiana* Kenfack & Ewango
Sapotaceae	*Manilkara pellegriniana* Tisserant & Silans
Sapotaceae	*Omphalocarpum* cf. *elatum* Miers
Sapotaceae	*Omphalocarpum elatum* Miers
Sapotaceae	*Pouteria* sp.
Sapotaceae	*Synsepalum dulcificum* (Schum. & Thonn.) Daniell
Sapotaceae	*Synsepalum letouzeyi* Aubrév.
Sapotaceae	*Synsepalum longecuneatum* De Wild.
Simaroubaceae	*Odyendya gabonensis* (Pierre) Engl.
Simaroubaceae	*Pierreodendron africanum* (Hook.f.) Little
Simaroubaceae	*Quassia sanguinea* Cheek & Jongkind
Simaroubaceae	*Quassia silvestris* Cheek & Jongkind
Thymelaeaceae	*Dicranolepis pulcherrima* Gilg.
Ulmaceae	*Trema orientalis* (L.) Blume

Violaceae	*Alexis* cf *cauliflora* (Oliv.) Pierre
Violaceae	*Rinorea dentata* (P.Beauv.) O. Kuntze
Violaceae	*Rinorea kamerunensis* Engl.
Violaceae	*Rinorea leophylla* Brandt.
Violaceae	*Rinorea oblongifolia* (C.H. Wright) Marqua
Violaceae	*Rinorea* sp.3
Violaceae	*Rinorea* sp.33
Violaceae	*Rinorea* sp.4
Violaceae	*Rinorea* sp.5
Violaceae	*Rinorea subintegrifolia* (P.Beauv.) O.Kuntze
Violaceae	*Rinorea woermanniana* (Butin) Engl.
Vochysiaceae	*Erismadelphus exsul* Mildbr.
Vochysiaceae	*Korupodendron songweanum* Litt & Cheek

CHAPTER FOUR

PATTERNS OF TREE DIVERSITY, ABOVE GROUND BIOMASS AND CARBON ALONG AN ELEVATIONAL GRADIENT IN TROPICAL FOREST: A CASE STUDY OF THE RUMPI FOREST RESERVE IN CAMEROON, WESTERN CENTRAL AFRICA

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Preface

An overview of tree diversity, above-ground biomass, and carbon stock along elevation gradients were evaluated and analyze in this chapter.

ABSTRACT

Tropical forest remains the most diverse ecosystem on earth, and stores considerable amounts of biomass and carbon. Despite its importance, sizable knowledge gaps surround the relationships among species diversity, plant biomass and carbon in different forest ecosystems. These knowledge gaps are particularly wide in tropical systems, and even more so in the African tropics. This study seeks to provide baseline data on species composition and vegetation structure, and to evaluate variation along elevational gradients for tree species diversity, above-ground biomass and carbon in 25 1-ha plots in the Rumpi Hills Forest Reserve, in Cameroon. Plots were sampled in 500 x 20 m transects, measuring trees and lianas with diameter at breast height ≥10 cm in four types of forest in the reserve. Results revealed high diversity, particularly in lowland forest. Overall, the study examined 12,037 individuals (Trees ≥ 10 cm dbh) in 441 species; mean numbers of species per plot were 112 species ha^{-1} in lowland, 81 species ha^{-1} in mid-elevation, 60 species ha^{-1} in submontane and 38 species ha^{-1} in montane forest. Above-ground biomass averaged 325.77±100 t ha^{-1}, and carbon averaged 162.88±50 t ha^{-1}. We found negative relationship between carbon and elevation (r^2 = 0.0618, $P < 0.05$), and a weak positive relationship between species diversity and carbon (r^2 = 0.34, $P < 0.05$), following regression analysis. Correspondence analysis suggested that lowland elevation, high species diversity and high carbon are associated while low carbon and low species diversity are associated. Our results indicate that high species diversity and occurrence of larger tree species are more important in carbon storage than elevation in RHFR. These findings are useful for management and land use planning of the unique forests in the Rumpi Hills Forest Reserve.

Keywords: Carbon, Lowland, Montane ecosystem, Tropical forest, Rumpi Hills Forest Reserve

4.1 INTRODUCTION

Terrestrial forest ecosystems remain major carbon sinks, and hold large stock of biomass. They mitigate climate change through sequestration of carbon in vegetation biomass. The vegetation gains carbon from productivity investment in aerial and roots of live trees, and loses carbon owing to aging, mortality, harvest, etc. (Myneni et al., 2001). Although tropical forests have high carbon storage capacity (Pan et al., 2011, Reich, 2011), they are threatened by anthropogenic activities such as deforestation, farming and urbanization. Currently, gaps in tropical forest dynamics and ecology exist; these gaps may hinder reliable predictions of forest responses to global change and development of efficient management strategies to minimize anthropogenic threats and optimize carbon storage capacity of forests (Zuidema et al., 2013).

Empirical findings pertaining to forest ecology have revealed that biodiversity correlates broadly with above-ground biomass and carbon stocks in forests, and that species diversity declines along elevational gradients (Asase et al., 2012; Day et al., 2013; Imani et al., 2017). Relationships between elevational gradients and carbon should be straightforward, but recent studies have revealed that it is not: different elevational patterns documented include hump-shaped, reversed hump-shaped, increasing multimodal relationships and no relationship at all (Lee and Chun 2016). In a recent study in tropical montane forests in southern Ecuador, biomass of lianas and the relative contribution of lianas to total above-ground biomass decrease with elevation and with a decrease of host trees (Fadrique and Homeier, 2016). Some studies have found positive correlations between tree diversity and above-ground biomass (Day et al., 2013), and others have established positive relationships between tree diversity and carbon stock in tropical forest (Asase et al., 2012).

To fill these knowledge gaps and to provide additional points of information from the African tropics, we carried out fine-scale and accurate measurements of biomass and carbon, tree species, tree sizes and tree densities along an elevational gradient in the Rumpi Hills Forest Reserve. The Rumpi Hills Forest Reserve is a protected tropical rainforest that is rich in endemic tree species; it is also relatively intact and understudied, and thus is an ideal choice for our investigation. This study seeks to establish baseline data on species composition and vegetation structure, and explore relationships among species biodiversity, elevation and carbon in the diverse tropical forests of the Rumpi Hills Forest Reserve.

4.2 MATERIALS AND METHODS

4.2.1 Study sites

The study area was in the Rumpi Hills Forest Reserve (RHFR) in Ndian Division, South West Region of Cameroon, stretching across latitudes 4.6-5.0°N and longitudes 8.8-9.4°E, with an elevational range of 50-1778 m. It covers an area of 453 km^2 (Sainge, 2016). The annual rainfall at the nearby village of Dikome Balue is 4933 mm, with August being the wettest month and December the driest (Thomas, 1996).

The study area was stratified into four vegetation communities (Letouzey, 1985), namely lowland evergreen rainforest, mid-elevation evergreen forest, submontane forest and montane cloud forest. The lowland forest covers the southern and part of the northeastern sections of the reserve, with an approximate extent of 185 km^2 at elevations of 50-300 m and 12 one-hectare plots were established. The mid-elevation evergreen forest covers the northern part of the reserve (ca. 133 km^2), at elevations of 300-800 m; eight one-hectare plots were established. Submontane forest occurs in the central, northeastern and eastern sectors of the reserve, with an extent of ca. 132 km^2 at elevations of 800-1600; three one-hectare plots were established. Finally, the montane cloud forest was in the eastern part of the reserve near Dikome Balue village with an extent of ca. 3 km^2 at elevations of 1600-1778 m; two one-hectare plots were established (Figure 4.1). Administratively, the montane cloud forest (1600-1778 m, at Mt Rata) falls outside of the Reserve, but it is a unique element in this montane system and should be considered with the other forest types.

4.2.2 Field sampling

In all, twenty-five 1-ha plots were sampled between February and June 2015 in the four forest types. Four types of vegetation cover (life forms) were considered in our survey: lianas, and trees ≥10 cm, ≥30 cm and ≥60 cm. Precise GPS coordinates were recorded at the beginning of each plot to assure repeatable plot locations; these coordinates are available in tabular form at http://hdl.handle.net/1808/25180.

Plots comprised transects that were 500 x 20 m, and sub-divided into 25 quadrats of 20 x 20 m. In mountainous areas, plots were located strategically so that 25 quadrats of 20 x 20 m representing one-hectare fit within a particular sampling area. Twenty-five plots were sampled for all trees and lianas ≥10 cm dbh. Information on vegetation, diameter at breast height, habitat, and species identification to morphospecies was recorded in the field. All live trees and lianas with dbh ≥10 cm were measured using a diameter tape, tagged using tree tag numbers and nails, and identified by two botanists. Voucher specimens were collected for all morphospecies. Plot data were used to estimate above-ground biomass, and carbon using the allometric equation of Chave et al., (2015). The height of each individual tree was calculated according to Djomo et al., (2016). Wood Specific Density (WSD) was assembled from the global wood density database (Zanne et al., 2009) and the African wood density database (Carsan et al., 2012). Biomass and carbon estimations were achieved for every individual tree, including for multiple stems. These values were summarized by plot and by forest type (Losi et al. 2003). Observational data were collected within our broader survey area, representing individuals with flowers or fruits, and particularly species that were not recorded in the general plot census. Plots were not established at 600-1200 m due to time constraint, difficulty to access this elevation and limited funding.

4.2.3 Forest type classification

A previous study recognized 267 forest types in Cameroon (Letouzey, 1985), of which seven are represented in our study area, broadly divided into four forest types: lowland, mid-elevation, submontane, and montane. Detailed descriptions of the different forest types are available in Letouzey, 1985.

4.2.4 Data analysis

Identification of specimens were carried out at the National Herbarium of Cameroon (YA) by matching specimens collected with existing herbarium sheets, and by consulting floras, published documents, and keys for the plants of the region (Hutchinson and Dalziel, 1954, 1958, 1963; Vivien and Faure, 1985; Keay, 1989; Thomas et al., 2003; Cheek et al., 2004; Harvey et al., 2004; Harvey et al., 2010; Onana, 2011, 2013). The final checklist was consolidated following the Angiosperm Phylogeny Group (APG III) classification (Judd et al., 1999; Angiosperm Phylogeny Group (APG III, 2009)).

Basal Area, Relative dominance, relative density, relative frequency was calculated using the formulas below. Fisher's alpha, Shannon-Wiener index (H'), and Simpson index were used as indices to compare species diversity among plant forms and elevations using the software package PAST version 2.17 (Hammer et al., 2001). This was based on 12 ha in lowland, 8 ha in mid-elevation, 3 ha in submontane and 2 ha in montane forest. Fisher's alpha was not calculated for lianas in montane forest because the values were too low. The distribution of variation in tree species diversity and carbon per hectare in different forest types was analysed using analysis of variance (ANOVA). The data were converted to binomials (0 and 1) and correspondent analysis (CA) was performed to establish the relationship among elevation, species diversity and carbon. Regression analysis was conducted with the aid of PAST version 2.17.

A non-destructive method was used to estimate above-ground biomass, and carbon stock to diameter at breast height, and wood Specific density (WD). Above-ground biomass and carbon were estimated for trees (dbh ≥10 cm) across forest types using the allometric equation of Chave et al., (2015) and tree height were estimated following Djomo et al., (2016).

Eq. (1) Basal Area (BA) = Area occupied by plant at breast height. (BA) = $pi*(1/2\text{dbh})^2 = pi*(\text{dbh})^2/4$. Basal area is the area occupied by a species.

Eq (2) $\text{Relative dominance} = \frac{\text{Basal area of species}}{\text{Basal area of all species}} \text{ X } 100$

Eq. (3) $\text{Relative density} = \frac{\text{Number of individuals of a species}}{\text{Total number of individuals}} \text{ X } 100$

Frequency is the number of quadrats in which a species is found in the entire sample

Eq. (4). $\text{Relative frequency} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \text{ X } 100$

Eq. (5) Importance Value Index (IVI) = Relative density + Relative dominance + Relative frequency

Eq. (6) Shannon-Weiner index (H') is the most convenient tool to measure diversity in 1-ha plots. This was achieved through the following formula:

$$H' = -\sum pilnpi$$

Where *pi* is the proportion of individual of a species (Number of individual of a species/total number of all species), ln is the natural logarithm. Thus, the natural logarithm of the number of species (lnS) is the maximum value of H'.

Eq. (7) $\mathrm{AGB} = 0.0559(pD^2H)$ (Chave et al., 2015)

Eq. (8) $\mathrm{H} = e^{1.321+0.482\ln D+0.027\ln p}$(Djomo et al., 2016)

Where AGB is above-ground dry biomass; *ρ* is wood density; *D* is dbh; ln is the natural logarithm, and *e* indicates the exponential function. Wood specific density was assembled from published sources such as the Global Wood Density Database (Dryad identifier: http://hdl.handle.net/10255/dryad.235) (Zanne et al. 2009), and the African Wood Density Database (http://worldagroforestry.org/sea/Products/AFDbases/WD/Index.htm) (Carsan et al., 2012). Species-specific wood densities were used for individuals identified to the species level. In cases in which species-specific wood densities were not available, mean values for the genus or family were used. For unidentified stems overall mean wood density for the data set was used (Baker et al., 2004).

We calculated carbon content as Carbon = Total above-ground biomass/2 (Brown, 1997; Chave et al., 2005; Lewis et al., 2009).

4.3 Results

4.3.1 Plant density and basal area by forest type

Density of trees with dbh ≥10 cm decreased with elevation (Figure 2). Mean density varied across forest types and elevation: 493 trees ha^{-1} (397-559 trees) in lowland, 450 trees ha^{-1} (376-531 trees) in mid-elevation, 485 trees ha^{-1} (263-649 trees) in sub-montane and 533 trees ha^{-1} (518-549 trees) in montane (Table 1). Mean basal area was associated with elevation: 35.3 m^2 ha^{-1} (26.8-44.2 m^2) in lowland, 26.9 m^2 ha^{-1} (20.9-32.4 m^2) in mid-elevation, 27.5 m^2 ha^{-1} (15.9-34.13 m^2) in sub-montane and 34.4 m^2 ha^{-1} (34.3-34.5 m^2) in montane forest. Overall tree density (multiple stems excluded) decreased with elevation: lowland (5916 trees), mid-elevation (3600 trees), sub-montane (1454 trees) and montane (1066 trees) (Table 4.1, Figure 4.2).

4.3.2 Elevational patterns

All trees with dbh ≥10 cm totaled 12,037 individuals in 441 species, 229 genera, and 63 families across the four forest types. Ninety-two individuals were not identified to species and genus, and nine individuals were not identified to family. The 92 individuals corresponded to 17 morphospecies, so the overall species richness of all trees ≥10 cm dbh was 458 morphospecies. The observational data provided records of an additional 254 individual trees in 62 families, 129 genera and 210 species, of which 132 species were not recorded in the sampling plots.

The Reserve overall holds a mean of 92 species ha^{-1} (ranging 36-140 species) for trees with dbh ≥10 cm. Lowland forest holds a mean of 115 species ha^{-1} (ranging 93-140 species), 84 species ha^{-1} (75-91 species) in mid-elevation forest, 59 species ha^{-1} (32-80 species) in submontane and 38 species ha^{-1} (35-40 species) in montane forest. Lianas with dbh ≥10 cm represent a mean of 4 species ha^{-1} (0-8 species) in lowland forest, 3 species ha^{-1} (0-7 species) in mid-elevation, and 1 species ha^{-1} (1-1 species) in submontane forest, no liana species were recorded in montane forest in this diameter class. Regression analysis showed a strong significant negative relationship between species richness and elevation ($r = 0.756$, $p < 0.05$;) across 25 ha plot in the Rumpi Hills Forest Reserve, Cameroon (Figure 3). Overall we found 24 species of lianas with dbh ≥10 cm in lowland forest, 17 species in mid-elevation, two species in submontane and no species in montane forest. The number of lianas correlated strongly with the number of trees with dbh ≥60 cm along the elevational gradient (Figure 4.4).

In all, 88.3% of trees and lianas were identified to species level, 89% to genus level, 99.3% to family level, and <1% entirely unidentified. A detailed summary of occurrence of species across different forest types is presented in Appendix 4.1.

4.3.3 Species richness within families

Lowland forest had the most families (53), followed by mid-elevation and submontane with 42 families each and montane with 25 families. In lowland forest, Fabaceae had the highest number of species, with 55 species in 566 individual trees, Annonaceae hold 21 species with 136 trees, Rubiaceae 21 species with 164 trees, Phyllanthaceae 17 species in 455 trees and Malvaceae 15 species in 190 trees. Rare families with one species each were Bignoniaceae (62 trees), Boraginaceae (2 trees), Cecropiaceae (55 trees), Medusandraceae (121 trees) and Erythroxylaceae (1 tree). In mid-elevation, Fabaceae was still the dominant family with 21 species in 370 trees, followed by Annonaceae 12 species in 139 trees, Malvaceae 10 species in 61 trees and

Euphorbiaceae (130 trees), Phyllanthaceae (182 trees), and Rubiaceae (28 trees) in nine species each. The rarest family in this vegetation type was Vochysiaceae with one species.

In submontane vegetation, Rubiaceae was the dominant family with 14 species in 100 trees, Euphorbiaceae nine species (97 trees), Meliaceae eight species (125 trees), Annonaceae (24 trees) and Apocynaceae (160) with 6 species each. The rarest families in this vegetation type with one species each were Achariaceae (68 trees), Alangiaceae (three trees), Medusandraceae (11 trees), Ochnaceae (one tree), Octoknemaceae (eight trees), and Simaroubaceae (eight trees). In montane forest, Rubiaceae was the dominant family with six species in 18 trees, Clusiaceae (169 trees) in five species, Salicaceae (13 trees) in four species and Malvaceae (47 trees) in three species. The rarest families with one species each were Achariaceae 91 trees; Anacardiaceae 54 trees; Putranjivaceae 37 trees; Asteraceae 14 trees; Phyllanthaceae 12 trees; Araliaceae six trees; Fabaceae and Melastomataceae with three trees each; and Cecropiaceae, Leptaulaceae, Sapindaceae, and Thymelaeaceae with one tree each.

4.3.4 Above-ground biomass and carbon estimation

The mean wood density of species in this study was 0.63 g cm^{-3}, ranging from 0.21 g cm^{-3} to 0.96 g cm^{-3}. Within the entire data set, 78.7% of species had WSD ranging from >0.5 to 0.8 g cm^{-3}, 12.3% had densities 0.21-0.5 g cm^{-3} and 9% >0.8 g cm^{-3}. Overall, above-ground biomass in Rumpi Hills was 8144.06 tons in 25 ha. There was great variation among the twenty-five hectares at different forest types (Table 1): mean AGB per hectare was 325.76 t ha^{-1} ranging from 129.1 t ha^{-1} in submonane to 585.3 t ha^{-1} in lowland forest. In lowland forest, the mean was 386.1±95.5 t ha^{-1} ranging from 282.4 t ha^{-1} to 585.3 t ha^{-1}, at mid-elevation, the mean was 252.64±48.58 t ha^{-1} (183.84-316.03 t ha^{-1}), the mean in submontane was 258.09±111.84 t ha^{-1}(129.1-327.84 t ha^{-1}) and montane forest records a mean of 357.76±5.96 t ha^{-1} (353.54-361.97 t ha^{-1}). These values varied significantly among forest types (ANOVA, $F_{8.414}$=10.14, P <0.01): biomass of mid-elevation and submontane forest was significantly lower than the biomass of the other forest types (Welch F test of unequal variances, df=15.4, P <0.02).

The overall total carbon estimate in the 25 1-ha plot was 4072.07 t, ranging from 64.55 t in submontane forest to 292.6 t in lowland forest; overall mean was 162.88±50.42 t per hectare. A weak significant negative association between carbon and elevation (r^2= 0.0618, p <0.05; Figure 5) was observed, with the amount of carbon declining from (292.6) tC ha^{-1} in lowland forest to (64.55) tC ha^{-1} in submontane forest (Table 4.1). Thus, the four forest types presented a mean carbon density of 193.06 t ha^{-1} (ranging 126.57-292.6 t ha^{-1}) in lowland forest, mean carbon density of 126.32 t ha^{-1} (ranging 91.92-154.6 t ha^{-1}) in mid-elevation, mean carbon density of 129.03 t ha^{-1} (ranging 64.55-163.92 t ha^{-1}) in submontane, and a mean carbon density of 178.88 t ha^{-1} (ranging 176.77-180.00 t ha^{-1}) in montane forest (Table 4.3). A weak positive relationship was manifested between carbon and number of species per hectare (r^2 = 0.34, P < 0.05; Figure 4.6). Correspondence analysis indicated axes 1 and 2 accounted for 60% of the total variance of the data, and it revealed two opposite associations: the correlations among lowland forest, high species diversity and high carbon in axis 1, and on the other hand mid-elevation, low species diversity and low carbon correlated (Figure 4.7).

Large trees (dbh ≥10 cm) in our study plots ranged 10-215 cm, with most trees representing dbh <50 cm (93.3%); only 6.7% of trees had dbh ≥50 cm. This difference reveals a high rate of regeneration of trees in the Reserve, which brings us to an assumption that the level of disturbance in the RHFR is low. However, of the 441 species with dbh ≥10 cm, 52 species had 5070 individuals out of the 12037 stems (42.1%), representing 66.6% of above-ground biomass; and 66.6% of carbon in the entire 25 ha plots (Table 4.4).

4.4 Discussion

Many authors have documented different tree densities across the different landscapes in Cameroon (Newberry and Gartlan, 1996; Thomas et al., 2003; Kenfack et al., 2007; Gonmadje et al., 2011; Djuikouo et al., 2014). Newberry and Gartlan, (1996) worked in Korup National Park (200-300 m asl) and Douala-Edea reserve (50-200 m), documenting tree densities of 461-481 trees ha^{-1} and 295 trees ha^{-1} respectively. Thomas et al., (2003) and Kenfack et al., (2007), in their studies of a 50-ha plot in Korup National Park, registered a mean tree density of 487 trees ha^{-1}. Generally, these results are in agreement with the overall mean density of stands (481 trees ha^{-1}) in the Rumpi Hills (lowland to Montane forest).

This study revealed that the RHFR is rich in species endemic to Cameroon. In total, 17 species were endemic to Cameroon with species such as *Deinbollia angustifolia*, and *Gambeya korupensis* that are endemic to the Korup and Rumpi Hills area. A further 43 species were endemic to the Lower Guinea Forest Block (Appendix 4.1). This high level of species diversity and endemism is corroborated by Mittermeier et al., (1999), Myers et al., (2000), Bergl et al., (2007) and Marchese, (2015), who classified the lowland and highland forests of west and central Africa as a global biodiversity hotspot and concentration of endemic species. We found a decrease in overall tree density and tree species diversity with elevation (Figure 4.2). Although species richness patterns generally decrease monotonically with elevation, some previous studies have found mid-elevational peaks along elevational gradients (McCain and Grytnes, 2010). It is worth noting that methodological factors including scale and sampling, and geographic factors can strongly influence elevational species richness. Elevational gradients are modulated by cascading and interlinked effects of biotic and abiotic factors such as rainfall, temperature and humidity, which vary among ecosystems and with spatial and temporal scale (Ali and Yan 2017).

The present study demonstrated a strong correlation between lianas and large tree diversity (Figure 4.6), suggesting a liana–host tree interaction, which agrees with studies that explain how large trees are important for liana abundance in tropical forest (Ewango, 2010; Ewango et al., 2015; Fadrique and Homeier, 2016). Lianas as structural parasites generally rely on trees for support (Parren, 2003; Ewango, 2010). These ideas align with the niche complementarity and mass ratio hypotheses of Ali and Yan, (2017), which explain the effect of functional diversity on carbon stock.

Most previous studies on biomass and carbon have been carried out in lowland forest (Brown, 1997; Djomo, 2010; Djomo et al., 2010; Djuikouo et al., 2010; Day et al., 2013; Chave et al., 2015; Djomo et al., 2016; Memiahge et al., 2016). The present study covers different forest types at different elevations, from the lowlands at 50 m to montane forest at 1778 m. Although biomass and carbon decreases with elevation, our results were not straight forward as lowland and montane forest reveals high biomass and carbon than mid-elevation and submontane forest (Figure 4.7). Based on the results obtained in this study, it plausible to suggest that lowland elevation, high species diversity and high carbon are associated while low carbon and low species diversity are associated.

Generally, the overall totals for biomass and carbon were high in RHFR per hectare compared to other sites in Africa (Sonwa et al., 2011). Our lowland forest with a mean biomass of 386.1 t ha^{-1} was slightly lower compared to other lowland tropical forests, with 402 t ha^{-1} in (Djuikouo et al., 2010), 404 t ha^{-1} in (Lewis et al., 2009), and 429 t ha^{-1} in the Congo Basin (Lewis et al., 2013). This is not surprising as the previous studies used the earlier formula by Chave et al., (2005) which differs from the more recently revised version of Chave et al., (2015) that was used in this study. Discrepancies are bound when the same data set is analyzed with different allometric equations (Brown et al., 1989; Brown, 1997; Chave et al., 2005; Djomo, 2010; Chave et al., 2015; Djomo et al., 2016).

Although mid-elevation and submontane forest showed lower values compared to lowland and montane forest, they still fell within the high end of the range among other studies in Africa (Brown, 1997; Makana, 2010; Djuikoko et al., 2010; Lewis et al., 2009; Lewis et al., 2013; Kupsch et al., 2014; Ekoungoulou et al., 2014; Kenfack et al., 2014; Memiaghe et al., 2016). The Rumpi Hills, on a per hectare basis, had its maximum biomass in a lowland plot of 585.3 t ha^{-1}, which accorded well with a hectare plot in the Monts de Cristal National Park in Gabon (619 t ha^{-1}), the highest value in the entire summary (Day et al., 2013). In a similar study in the Albertine Rift (Imani et al., 2017), biomass ranged from 168 t ha^{-1} in upper montane to 290 t ha^{-1} in middle montane forest, lower than the values we recorded. Thus, the intact lowland to montane forest continuum in the Rumpi Hills is a potential carbon sink and site for the implementation of REDD+ mechanisms, climate change and forest dynamics.

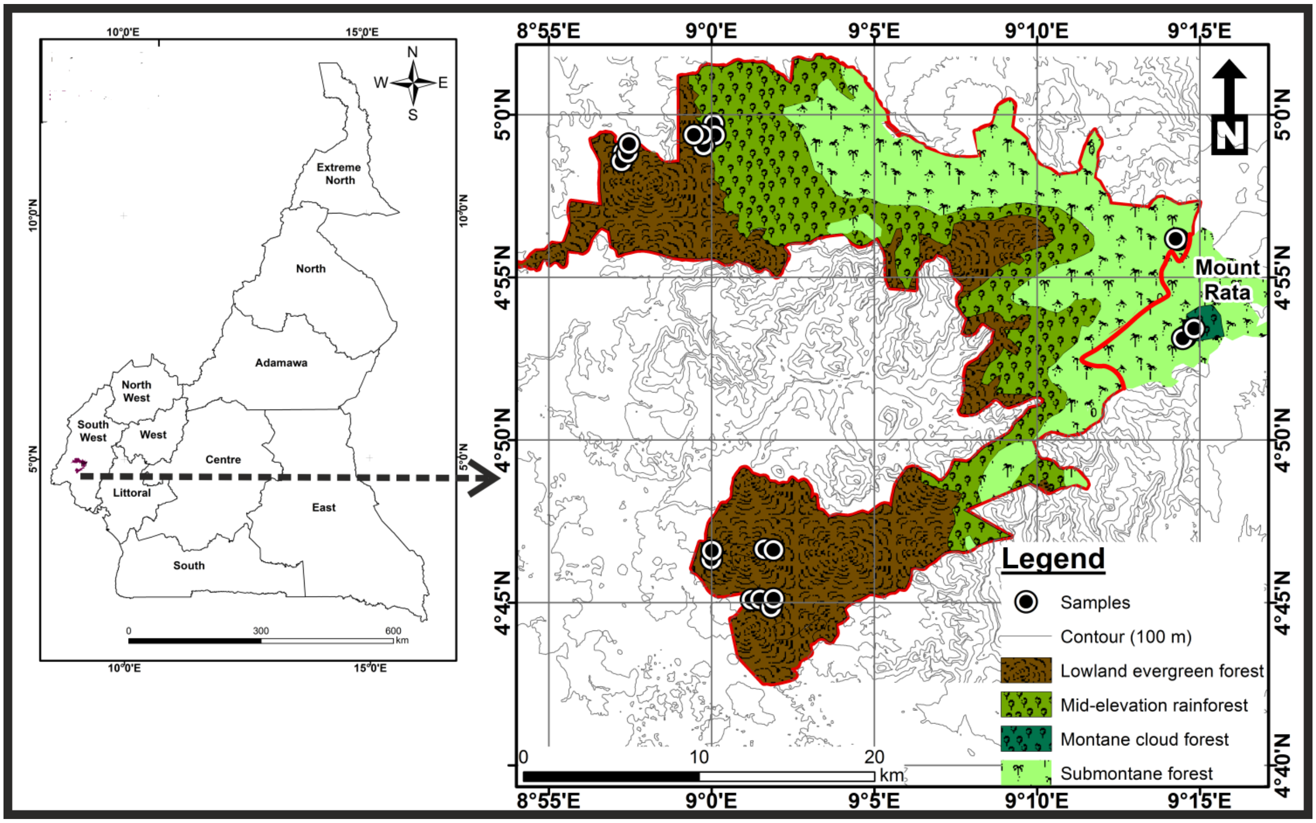

Figure 4.1 Sample points and four plant communities at the Rumpi Hills Forest Reserve, Cameroon

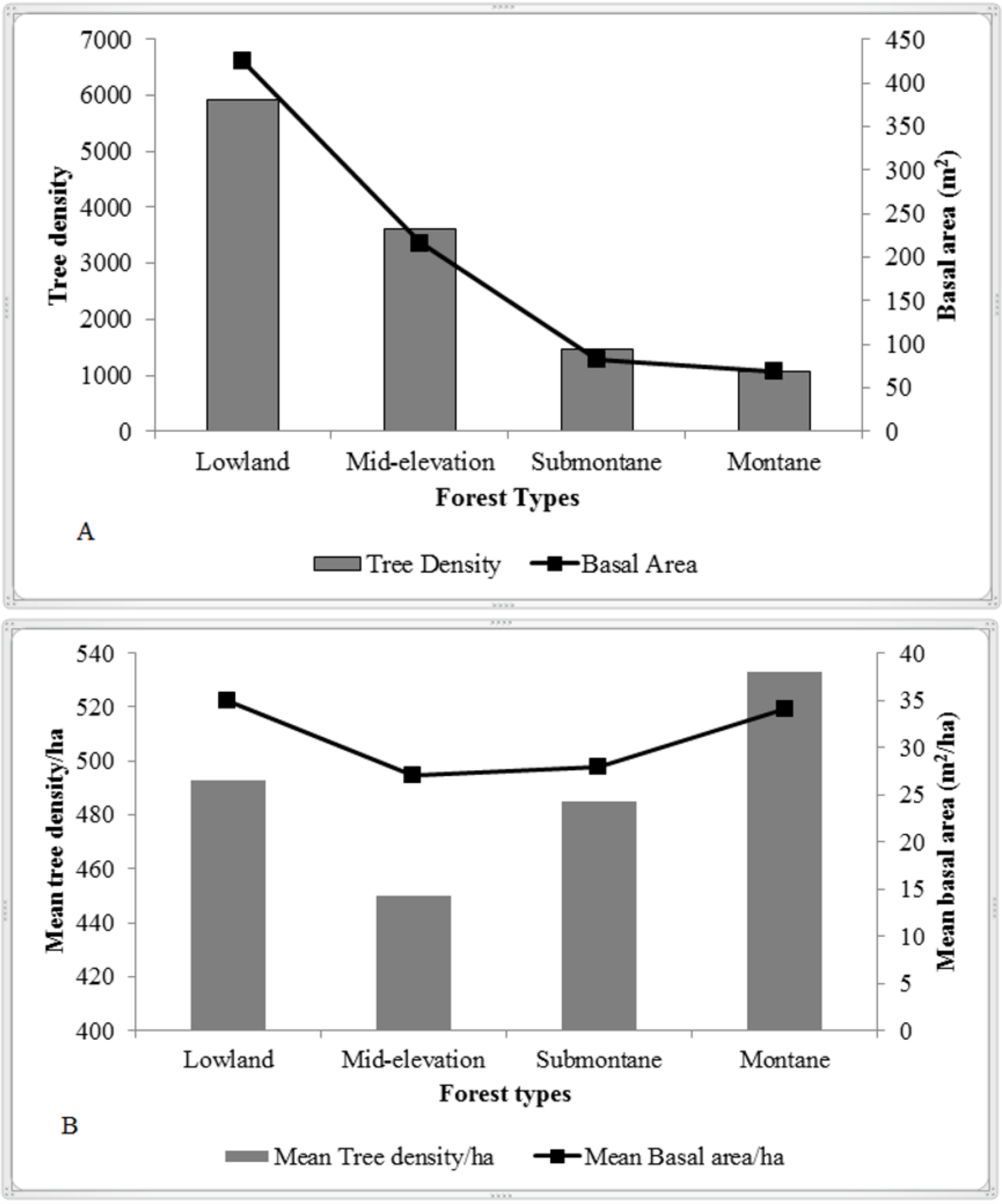

Figure 4.2 (A) Variation of tree density and basal area, (B) Mean tree density/ha, (C) Mean basal area m^2/ha in four forest types in the Rumpi Hills Forest Reserve, Cameroon

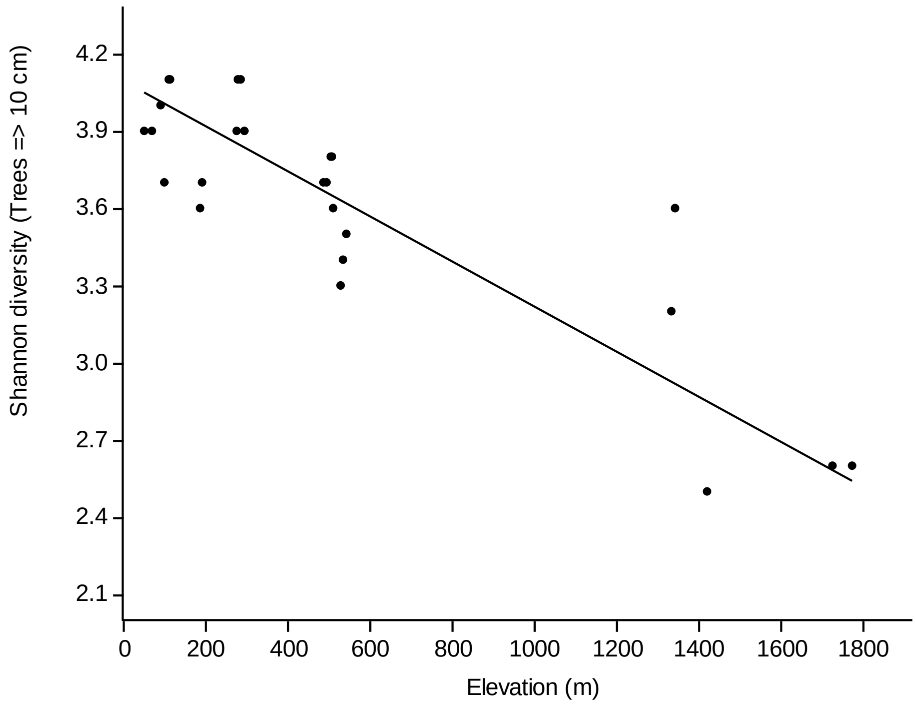

Figure 4.3 Regression analyses showing a strong significant negative relationship between species richness and elevation ($r^2 = 0.756$, $p < 0.05$;) across 25 ha plot in the Rumpi Hills Forest Reserve, Cameroon.

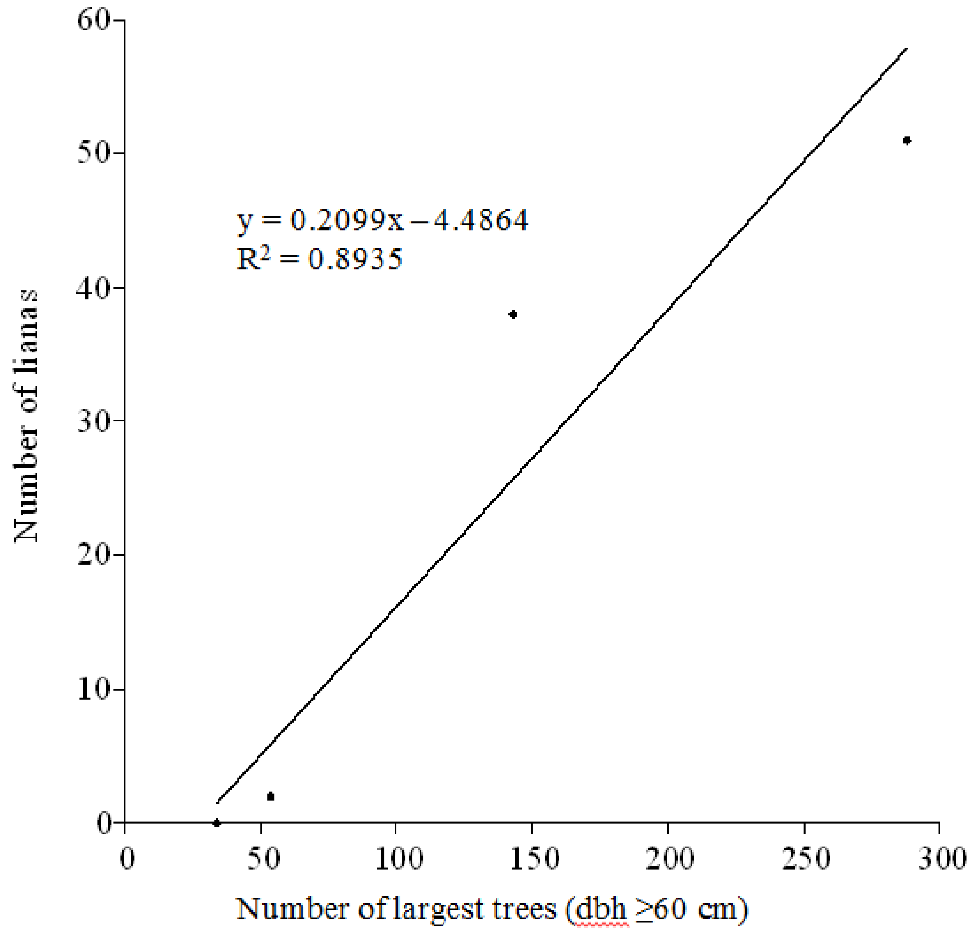

Figure 4.4 Correlation of number of lianas and number of large trees ≥60 cm (r^2 = 0.8935, P <0.05).

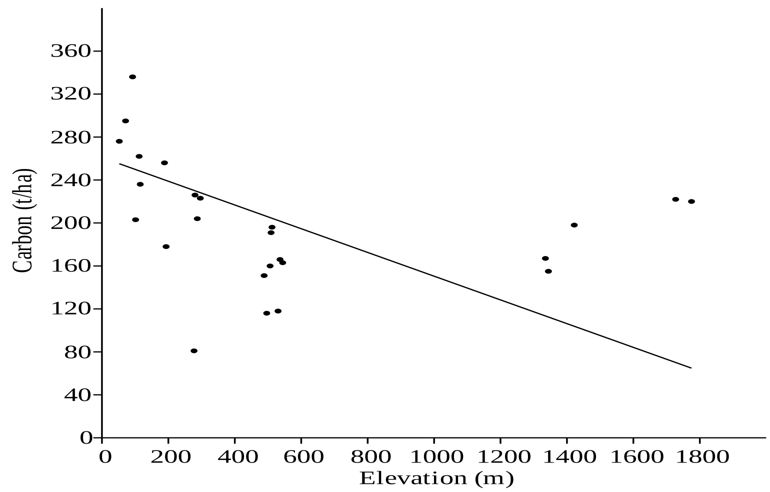

Figure 4.5 Association between carbon (tC/ha) and elevation (m) of trees with dbh ≥10 cm recorded in 25 1-ha plots in the Rumpi Hills Forest Reserve, Cameroon. The relationship has a slope of 0.061, which is significantly different from a slope of zero ($P < 0.05$), y=-0.11x+260.9.

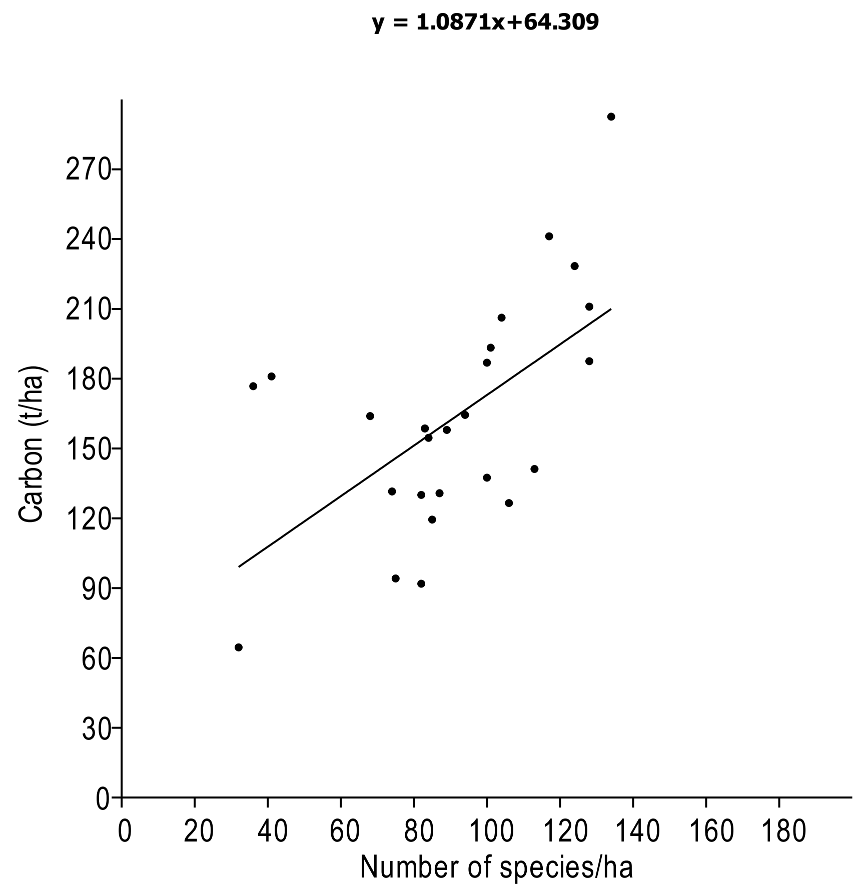

Figure 4.6 Association between carbon (tC/ha) and number of species/ha with dbh ≥10 cm recorded in 25 1-ha plots in the Rumpi Hills Forest Reserve, Cameroon; $r^2 = 0.34$; $y = 1.0871x + 64.30$

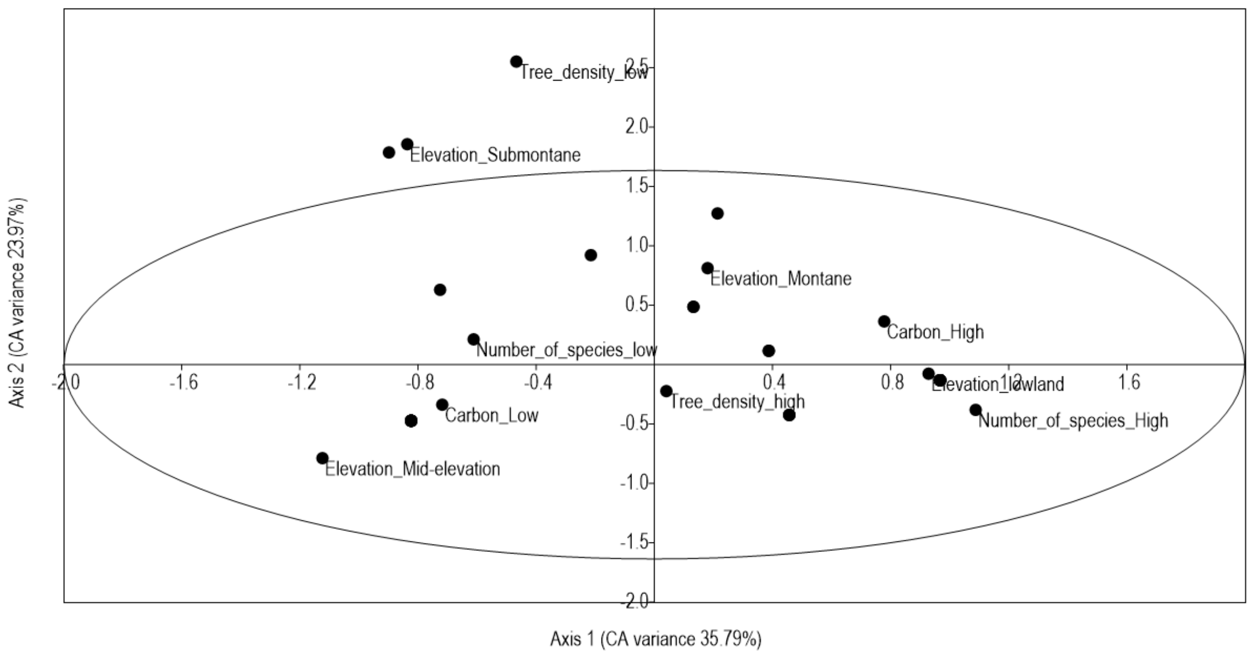

Figure 4.7 Correspondence analysis reflecting high tree density, number of species, carbon in lowland and Montane forest and low tree density, number of species, and carbon in mid-elevation and submontane forest of the Rumpi Hills forest Reserve in Cameroon.

Table 4.1 Tree diversity, above ground biomass (AGB), and carbon in lowland, mid-elevation, submontane, and montane cloud forest. BA (basal area), N (tree density), SR (species richness), SW (Shannon-Weiner index).

Plot	Forest type	Tree/ha (N)	BA (m^2/ha)	SR	SW	AGB (t/ha)	Carbon (t/ha)
1	Lowland	397	29	93	4.54	329	165
2	Lowland	493	44.5	140	4.95	585	293
3	Lowland	544	41.1	130	4.87	456	228
4	Lowland	538	43.1	117	4.77	483	241
5	Lowland	538	38.1	130	4.88	375	188
6	Lowland	559	37.6	129	4.87	422	211
7	Lowland	513	39.1	112	4.72	413	206
8	Lowland	503	29.2	115	4.75	282	141
14	Lowland	469	26.8	107	4.67	253	127
15	Lowland	480	27.7	102	4.63	275	137
16	Lowland	423	33.8	100	4.62	387	193
17	Lowland	459	35.1	101	4.63	374	187
9	Submontane	542	32.4	80	4.39	317	159
10	Submontane	649	34.1	66	4.21	328	164
13	Submontane	263	15.9	32	3.47	129	65
11	Montane	548	34.5	40	3.71	362	181
12	Montane	518	33.3	35	3.58	354	177
18	Mid-elevation	475	28.1	81	4.41	260	130
19	Mid-elevation	464	21.9	75	4.33	188	94
20	Mid-elevation	490	27.8	91	4.52	262	131
21	Mid-elevation	531	31.3	89	4.5	316	158
22	Mid-elevation	447	26.7	87	4.48	239	119
23	Mid-elevation	376	21	85	4.44	184	92
24	Mid-elevation	436	32.4	85	4.45	309	155
25	Mid-elevation	381	26.9	81	4.39	263	132
Total		12036	791.4	2303	111.78	8144	4072
Mean		481.44	31.66	92.12	4.47	326	163
Standard deviation		76.8348	6.88	28.59	0.38	101	50

Table 4.2 Summary of total number of individuals, basal area, number of species, and Shannon diversity for the different life forms recorded in four forest types at various size classes in the Rumpi Hills Forest Reserve, Cameroon

Forest type	Life form	Size class (cm dbh)	N	BA	S	Fisher's alpha	H'
Lowland	Lianas	≥10	51	0.96	24	17.69	2.96
Lowland	Trees	≥10	4617	106.94	308	74.3	4.67
Lowland	Trees	≥30	1008	135.79	165	56.06	4.32
Lowland	Trees	≥60	288	183.20	83	39.06	3.79
Mid-elevation	Lianas	≥10	38	0.56	17	11.81	2.19
Mid-elevation	Trees	≥10	2836	68.19	172	40.3	4.03
Mid-elevation	Trees	≥30	621	82.66	83	25.75	3.79
Mid-elevation	Trees	≥60	143	68.67	41	19.22	3.01
Submontane	Lianas	≥10	2	0.03	2	0	0.69
Submontane	Trees	≥10	1181	29.48	116	31.88	3.94
Submontane	Trees	≥30	219	28.49	55	23.61	3.45
Submontane	Trees	≥60	54	27.25	21	12.62	2.66
Montane	Lianas	≥10	0	0	0	0	0
Montane	Trees	≥10	786	22.87	46	10.66	2.98
Montane	Trees	≥30	245	30.76	24	6.59	2.42
Montane	Trees	≥60	34	16.6	13	7.69	2.25

Fisher's alpha was based on 12 ha in lowland, 8 ha in mid-elevation, 3 ha in submontane and 2 ha in montane forest. Fisher's alpha was not calculated for lianas in montane forest (0) because the values were too low. N=Number of individuals stands, BA=Basal Area, S= Number of Species, Fisher's= Fisher's alpha, H'= Shannon-wiener diversity index. Basal area includes all multiple stems for each individual stem. Multiple stems excluded in all other parameters.

Table 4.3 Summary of biomass, and carbon in four forest types across Rumpi Hills Forest Reserve, Cameroon

Plot	Forest Types	AGB (t ha^{-1})	Carbon (t ha^{-1})
1	Lowland	329	165
2	Lowland	585	293
3	Lowland	456	228
4	Lowland	483	241
5	Lowland	375	188
6	Lowland	422	211
7	Lowland	413	206
8	Lowland	282	141
14	Lowland	253	127
15	Lowland	275	137
16	Lowland	387	193
17	Lowland	374	187
Total		4,633	2,317
Mean		386.1	193.1
Standard deviation		95.5	48
18	Mid-Elevation	260	130
19	Mid-Elevation	188	94
20	Mid-Elevation	262	131
21	Mid-Elevation	316	158
22	Mid-Elevation	239	119
23	Mid-Elevation	184	92
24	Mid-Elevation	309	155
25	Mid-Elevation	263	132
Total		2,021.1	1,011
Mean		252.6	126.3
Standard deviation		48.6	24.3
9	Submontane	317	159
10	Submontane	328	164
13	Submontane	129	65
Total		774	387

Mean		258	129
Standard deviation		112	56
11	Montane	362	181
12	Montane	354	177
Total		716	357.8
Mean		357.8	178.9
Standard deviation		6	3

Table 4.4 Summary of 52 species with biomass, and carbon in the Rumpi Hills Forest Reserve, Cameroon

Species	Abundance	AGB (t ha^{-1})	Carbon (t ha^{-1})
Scyphocephalium mannii	53	520.5	260.3
Pycnanthus angolensis	187	429.4	214.7
Cola verticilata	168	227.4	113.7
Oubanguia alata	813	296.7	148.4
Korupiodendron songweanum	165	216.5	108.2
Protomegabaria stapfiana	339	198.8	99.4
Piptadeniastrum africanum	40	177.8	88.9
Vepris soyauxii	27	166.3	83.1
Berlinia brateosa	60	133.6	66.8
Santiria balsamifera	156	132.3	66.1
Syzygium rowlandii	55	121.9	60.9
Strombosia sp.1	184	129.1	64.5
Irvingia gabonensis	61	113.1	56.5
Pseudospondias microcarpa	79	103.3	51.6
Erythrophleum ivorensis	3	124.8	62.4
Strombosiopsis tetrandra	175	117.6	58.8
Strombosia grandifolia	138	139.1	69.5
Eriocoelum macrocarpum	95	109.4	54.7
Staudtia kamerunensis	71	85.3	42.6
Carapa oreophilia	137	81.8	40.9

Pellegriniodendron diphyllum	19	65.2	32.6
Coula edulis	46	65.7	32.8
Homalium longistylum	82	66	33
Xylopia africana	133	80	40
Vitex grandifolia	119	68.1	34
Margaritaria discoidea	37	62	31
Lecomtedoxa klaineana	4	66	33
Trichoscypha cf oliveri	55	60.5	30.3
Anthonotha macrophylla	161	69.3	34.7
Coelocaryon preussi	46	55.9	28
Albizia adianthifolia	46	58	29
Hypodaphnis zenkeri	45	55	27.5
Sapium ellipticum	19	54.8	27.4
Trichoscypha sp.10	59	54.8	27.4
Desbordesia glaucescens	4	56.4	28.2
Gambeya africanum	28	53.3	26.7
Musanga cecropioides	118	56.4	28.2
Gambeya subnudum	104	52.6	26.3
Poga oleosa	7	53.4	26.7
Terminalia ivorensis	2	60.1	30.1
Dacryodes edulis	136	52	26
Mammea africana	179	55.7	27.9
Vitex sp.3	33	50.9	25.5

Strombosia pustulata	151	58.2	29.1
Alstonia boonei	10	50.2	25.1
Talbotiella korupensis	94	47	23
Zanthoxylon gilletii	72	46.6	23.4
Afrostyrax lepidophyllus	73	42	21
Staudtia gabunensis	36	46	23
Barteria fistulosa	33	50.5	25.3
Omphalocarpum elatum	30	41.4	20.7
Symphonia globulifera	83	44	22
Total	5070	5422.7	2711.4
General Total in survey	12036	8144.1	4072.1
Percentage	42.1	66.6	66.6

Appendix 4.1. Species occurrence in the different forest types in the Rumpi Hills Forest Reserve, Cameroon

Family	Species	Lowland	Mid-elevation	Montane	Submontane	IUCN Status	Endemic to Cameroon	Cameroon Volcanic Line/Guinea Forest
Achariaceae	*Dasylepis thomasii*	18	-	91	-	VU	-	Endemic
Achariaceae	*Scottellia klaineana*	7	-	-	-	LC	-	-
Alangiaceae	*Alangium chinense*	-	-	-	3	LC	-	-
Anacardiaceae	*Antrocaryon micraster*	3	-	-	-	LC	-	-
Anacardiaceae	*Antrocaryon* sp.	1	-	-	1	-	-	-
Anacardiaceae	*Pseudospondias microcarpa*	36	42	-	-	NE	-	Endemic
Anacardiaceae	*Sorindeia grandifolia*	6	-	-	-	LC	-	-
Anacardiaceae	*Sorindeia juglandifolia*	5	5	-	-	LC	-	-
Anacardiaceae	*Trichoscypha acuminata*	12	-	-	-	LC	-	-
Anacardiaceae	*Trichoscypha cf oliveri*	1	54	-	-	LC	-	-
Anacardiaceae	*Trichoscypha patens*	2	1	-	-	LC	-	-
Anacardiaceae	*Trichoscypha preussii*	16	-	-	-	-	-	-
Anacardiaceae	*Trichoscypha* sp.10	-	-	53	-	-	-	-
Anacardiaceae	*Trichoscypha* sp.12	3	-	-	-	-	-	-
Anacardiaceae	*Trichoscypha* sp.4	16	1-	-	-	-	-	-
Anacardiaceae	*Trichoscypha* sp.6	5	-	-	-	-	-	-

Anacardiaceae	*Trichoscypha* sp.9	2	-	1	-	-	-	-
Anisophylleaceae	*Anisophyllea meniaudii*	2	-	-	-	DD	-	-
Anisophylleaceae	*Anisophyllea polyneura*	2	22	-	-	LC	-	-
Anisophylleaceae	*Anisophyllea purpurascens*	2	5-	-	-	DD	-	-
Anisophylleaceae	*Anisophyllea sororia*	6	36	-	-	DD	-	-
Anisophylleaceae	*Poga oleosa*	7	-	-	-	DD	-	-
Annonaceae	*Annickia chlorantha*	37	36	-	-	LC	-	-
Annonaceae	*Cleistopholis patens*	3	2	-	-	LC	-	-
Annonaceae	*Cleistopholis staudtii*	3	6	-	-	NT	-	-
Annonaceae	*Hexalobus* sp.	1	-	-	-	-	-	-
Annonaceae	*Isolona campanulata*	1	-	-	-	LC	-	-
Annonaceae	*Monodora brevipes*	1	-	-	-	LC	-	-
Annonaceae	*Monodora myristica*	-	-	-	-	LC	-	-
Annonaceae	*Pachypodanthium staudtii*	5	-	-	-	LC	-	-
Annonaceae	*Piptostigma oyemense*	13	15	-	-	-	-	-
Annonaceae	*Piptostigma pilosum*	1	-	-	-	LC	-	-
Annonaceae	*Piptostigma* sp.	-	9	-	-	-	-	-
Annonaceae	*Polyanthia suaveolens*	28	-	2	-	LC	-	-
Annonaceae	*Polyceratocarpus parviflorus*	1	43	-	-	LC	-	-
Annonaceae	*Uvariastrum pynaertii*	1-	-	-	-	LC	-	-
Annonaceae	*Uvariodendron connivens*	13	5	-	-	NT	-	Endemic
Annonaceae	*Uvariodendron giganteum*	-	-	-	-	NT	-	-
Annonaceae	*Uvariopsis korupensis*	1	5	-	-	EN	Endemic	-

Annonaceae	*Uvariopsis submontana*	-	-	-	-	EN	Endemic	-
Annonaceae	*Xylopia acutiflora*	7	9	-	-	LC	-	-
Annonaceae	*Xylopia aethiopica*	4	3	-	-	LC	-	-
Annonaceae	*Xylopia africana*	1	-	121	-	VU	-	Endemic
Annonaceae	*Xylopia hypolampra*	1	-	-	-	LC	-	-
Annonaceae	*Xylopia* sp.3	-	1	-	-	-	-	-
Annonaceae	*Xylopia* sp.I	1	-	-	-	-	-	-
Annonaceae	*Xylopia staudtii*	1	5	-	-	LC	-	-
Annonaceae	*Xylopia villosa*	3	-	-	-	LC	-	-
Apocynaceae	*Alstonia boonei*	7	3	-	-	LC	-	-
Apocynaceae	*Funtumia elastica*	21	4	-	-	LC	-	-
Apocynaceae	*Hunteria umbellata*	12	-	-	-	LC	-	-
Apocynaceae	*Pleiocarpa bicarpellata*	3	-	-	-	LC	-	-
Apocynaceae	*Pleiocarpa* sp.	-	-	1-	-	-	-	-
Apocynaceae	*Rauvolfia caffra*	-	1	-	-	LC	-	-
Apocynaceae	*Rauvolfia vomitoria*	5	4	-	-	LC	-	-
Apocynaceae	*Tabernaemontana brachyantha*	75	152	-	-	LC	-	-
Apocynaceae	*Tabernaemontana crassa*	18	16	-	-	LC	-	-
Apocynaceae	*Tabernaemontana ventricosa*	-	-	42	-	LC	-	-
Apocynaceae	*Voacanga africana*	-	-	-	-	LC	-	-
Araliaceae	*Polyscias fulva*	-	-	-	-	NT	-	-
Araliaceae	*Schefflera abyssinica*	-	-	6	-	LC	-	-
Asteraceae	*Vernonia conferta*	-	-	14	-	LC	-	-

Asteraceae	*Vernonia frondosa*	-	1	-	-	LC	-	-
Bignoniaceae	*Kigelia africana*	62	57	-	-	LC	-	-
Bombacaceae	*Bombax buenopozense*	1	-	-	-	LC	-	-
Bombacaceae	*Ceiba pentandra*	1	-	-	-	LC	-	-
Boraginaceae	*Cordia* sp.	2	6	-	-	-	-	-
Burseraceae	*Canarium schweinfurthii*	6	2	-	-	LC	-	-
Burseraceae	*Canthium* sp.	-	1	-	-	-	-	-
Burseraceae	*Dacryodes edulis*	87	49	-	-	LC	-	-
Burseraceae	*Dacryodes klaineana*	1	4	-	-	LC	-	-
Burseraceae	*Santiria balsamifera*	86	31	-	-	LC	-	-
Caricaceae	*Cylicomorpha solmsii*	-	-	-	-	VU	Endemic	-
Cecropiaceae	*Musanga cecropioides*	55	59	-	-	LC	-	-
Cecropiaceae	*Myrianthus arboreus*	-	-	1	-	LC	-	-
Cecropiaceae	*Myrianthus preussii*	-	-	-	-	NT	-	Endemic
Chrysobalanaceae	*Chrysobalanus icaco*	15	-	-	-	LC	-	-
Chrysobalanaceae	*Dactyladenia pallescens*	2	-	-	-	LC	-	-
Chrysobalanaceae	*Dactyladenia staudtii*	4	1	-	-	LC	-	-
Chrysobalanaceae	*Magnistipula* aff. *cuneatifolia*	1	-	-	-	EN	-	-
Chrysobalanaceae	*Magnistipula glaberrima*	11	-	-	-	NT	-	-
Chrysobalanaceae	*Maranthes kerstingii*	-	-	-	-	LC	-	-
Chrysobalanaceae	*Parinari chrysophylla*	7	-	-	-	LC	-	-
Chrysobalanaceae	*Parinari excelsa*	1	-	-	-	LC	-	-
Clusiaceae	*Allanblackia gabonensis*	2	-	-	-	VU	-	Endemic

Clusiaceae	*Endodesmia calophylloides*	9	-	-	-	LC	-	-
Clusiaceae	*Garcinia cf polyantha*	-	-	71	-	-	-	-
Clusiaceae	*Garcinia conrauana*	3	-	-	-	NT	-	-
Clusiaceae	*Garcinia gnetoides*	1	4	-	-	LC	-	-
Clusiaceae	*Garcinia kola*	4	4	-	-	VU	-	-
Clusiaceae	*Garcinia mannii*	46	43	2	-	LC	-	-
Clusiaceae	*Garcinia polyantha*	-	-	68	-	-	-	-
Clusiaceae	*Garcinia* sp.1	-	-	8	-	-	-	-
Clusiaceae	*Garcinia staudtii*	2	-	-	-	NT	-	Endemic
Clusiaceae	*Mammea africana*	35	144	-	-	LC	-	-
Clusiaceae	*Pentadesma butryacea*	1	-	-	-	LC	-	-
Clusiaceae	*Pentadesma grandifolia*	26	-	-	-	-	-	-
Clusiaceae	*Symphonia globulifera*	15	33	2-	-	LC	-	-
Combretaceae	*Strephonema pseudocola*	22	1	-	-	LC	-	-
Combretaceae	*Terminalia ivorensis*	2	-	-	-	LC	-	-
Combretaceae	*Terminalia superba*	4	-	-	-	LC	-	-
Dichapetalaceae	*Tapura africana*	53	1	-	-	LC	-	-
Ebenaceae	*Diospyros bipindensis*	3	-	-	-	LC	-	-
Ebenaceae	*Diospyros cinnabarina*	3	-	-	-	LC	-	-
Ebenaceae	*Diospyros gabunensis*	46	-	-	-	LC	-	-
Ebenaceae	*Diospyros gracilescens*	6	-	-	-	LC	-	-
Ebenaceae	*Diospyros hoyleana*	14	-	-	-	LC	-	-
Ebenaceae	*Diospyros iturensis*	11	-	-	-	LC	-	-

Ebenaceae	*Diospyros kamerunensis*	5	-	-	-	LC	-	-
Ebenaceae	*Diospyros korupensis*	4	1	-	-	VU	Endemic	-
Ebenaceae	*Diospyros* sp.	2	-	-	-	-	-	-
Ebenaceae	*Diospyros* sp.4	14	-	-	-	-	-	-
Ebenaceae	*Diospyros* sp.5	11	-	-	-	-	-	-
Ebenaceae	*Diospyros suaveolens*	2	4	-	-	LC	-	-
Ebenaceae	*Diospyros zenkeri*	17	2	-	-	LC	-	-
Erythroxylaceae	*Erythroxylum mannii*	1	-	-	-	LC	-	-
Euphorbiaceae	*Cleistanthus letouzeyi*	31	33	-	-	VU	-	Endemic
Euphorbiaceae	*Croton sylvaticus*	-	1	-	-	LC	-	-
Euphorbiaceae	*Dichostemma glaucescens*	88	3	-	-	LC	-	-
Euphorbiaceae	*Discoclaoxylon hexandrum*	1	4	-	-	LC	-	-
Euphorbiaceae	*Discoglypremna caloneura*	7	7	-	-	LC	-	-
Euphorbiaceae	*Elaeophorbia drupifera*	-	-	-	-	LC	-	-
Euphorbiaceae	*Euphorbia* sp.2	-	-	-	-	-	-	-
Euphorbiaceae	*Jatropha curcas*	-	-	-	-	LC	-	-
Euphorbiaceae	*Klaineanthus gaboniae*	63	6	-	-	LC	-	-
Euphorbiaceae	*Macaranga monandra*	23	27	-	-	LC	-	-
Euphorbiaceae	*Macaranga* sp.	-	-	1	-	-	-	-
Euphorbiaceae	*Macaranga spinosa*	2	-	-	-	LC	-	-
Euphorbiaceae	*Mareya micrantha*	5	-	-	-	LC	-	-
Euphorbiaceae	*Mareyopsis longifolia*	33	68	-	-	LC	-	-
Euphorbiaceae	*Neoboutonia glabrescens*	1	12	-	-	-	-	-

Euphorbiaceae	*Ricinodendron heudelotii*	2	-	-	-	LC	-	-
Euphorbiaceae	*Sapium ellipticum*	3	2	9	-	-	-	-
Euphorbiaceae	*Tetrorchidium didymostemon*	2	-	-	-	LC	-	-
Fabaceae	*Afzelia bella*	2	1	-	-	LC	-	-
Fabaceae	*Afzelia bipindensis*	1	-	-	-	VU	-	-
Fabaceae	*Afzelia pachyloba*	1	-	-	-	VU	-	-
Fabaceae	*Albizia adianthifolia*	23	23	-	-	LC	-	-
Fabaceae	*Albizia ferruginea*	4	1	-	-	LC	-	-
Fabaceae	*Albizia* sp.	1	-	-	-	-	-	-
Fabaceae	*Albizia* sp.4	-	5	-	-	-	-	-
Fabaceae	*Albizia zygia*	-	1	-	1	LC	-	-
Fabaceae	*Amphimas ferrugineus*	4	2	-	-	LC	-	-
Fabaceae	*Angylocalyx oligophyllus*	2	-	-	-	LC	-	-
Fabaceae	*Anthonotha cladantha*	9	-	-	-	LC	-	-
Fabaceae	*Anthonotha fragrans*	13	-	-	-	LC	-	-
Fabaceae	*Anthonotha lamprophylla*	17	3	-	-	LC	-	-
Fabaceae	*Anthonotha macrophylla*	73	59	-	-	LC	-	-
Fabaceae	*Aphanocalyx microphyllus*	-	-	-	1	LC	-	-
Fabaceae	*Baikiaea insignis*	1	-	-	-	LC	-	-
Fabaceae	*Baphia buettneri*	9	1	-	-	NT	-	Endemic
Fabaceae	*Baphia capparidifolia*	15	1	-	-	LC	-	-
Fabaceae	*Baphia laurifolia*	11	3	-	-	LC	-	-
Fabaceae	*Baphia* sp.	2	-	-	-	-	-	-

Fabaceae	*Berlinia auriculata*	36	-	-	-	LC	-	-
Fabaceae	*Berlinia bracteosa*	35	24	-	-	LC	-	-
Fabaceae	*Berlinia hollandii*	3	-	-	-	LC	-	-
Fabaceae	*Calpocalyx dinklagei*	5	-	-	-	LC	-	-
Fabaceae	*Calpocalyx heitzii*	8	-	-	-	NT	-	Endemic
Fabaceae	*Copaifera mildbraedii*	1	-	-	-	LC	-	-
Fabaceae	*Crudia* sp.	5	-	-	-	-	-	-
Fabaceae	*Cryptosepalum cougolanum*	1	-	-	-	-	-	-
Fabaceae	*Dialium bipindense*	1	-	-	-	LC	-	-
Fabaceae	*Dialium dinklagei*	1	-	-	-	LC	-	-
Fabaceae	*Dialium pachyphyllum*	15	5	-	-	LC	-	-
Fabaceae	*Didelotia africana*	5	-	-	-	LC	-	-
Fabaceae	*Didelotia morelii*	2	-	-	-	LC	-	-
Fabaceae	*Distemonanthus benthamianus*	1	-	-	-	LC	-	-
Fabaceae	*Erythrina milbraedii*	1	-	-	-	LC	-	-
Fabaceae	*Erythrophleum ivorensis*	3	-	-	-	LC	-	-
Fabaceae	*Gilbertiodendron demonstrans*	1	-	-	-	NT	-	Endemic
Fabaceae	*Gilbertiodendron dewevrei*	7	-	-	-	LC	-	-
Fabaceae	*Gilbertiodendron* sp.2	15	-	-	-	-	-	-
Fabaceae	*Hylodendron gabunense*	1	-	-	-	LC	-	-
Fabaceae	*Hymenostegia korupensis*	17	-	-	-	LC	-	-
Fabaceae	*Leonardoxa africana*	4	192	-	-	LC	-	Endemic
Fabaceae	*Microberlinia bisulcata*	1	-	-	-	VU	-	Endemic

Fabaceae	*Newtonia griffoniana*	3	7	-	-	LC	-	-
Fabaceae	*Parkia bicolor*	6	-	-	-	LC	-	-
Fabaceae	*Parkia* sp.	3	-	-	-	-	-	-
Fabaceae	*Pellegriniodendron diphyllum*	19	-	-	-	LC	-	-
Fabaceae	*Pentaclethra macrophylla*	1	-	-	-	LC	-	-
Fabaceae	*Piptadeniastrum africanum*	36	4	-	-	LC	-	-
Fabaceae	*Plagiosiphon longitubus*	-	3	-	-	LC	-	Endemic
Fabaceae	*Pterocarpus soyauxii*	3	-	-	-	LC	-	-
Fabaceae	*Talbotiella korupensis*	59	32	-	-	EN	Endemic	-
Fabaceae	*Tetraberlinia bifoliolata*	12	-	-	-	LC	-	-
Fabaceae	*Tetraberlinia korupensis*	11	-	-	-	EN	Endemic	-
Fabaceae	*Tetraberlinia polyphylla*	1	-	-	-	-	-	-
Fabaceae	*Tetrapleura tetraptera*	-	1	-	-	LC	-	-
Fabaceae	*Zenkerella citrina*	6	1	3	-	NT	-	Endemic
Gentianaceae	*Anthocleista schweinfurthii*	3	-	-	-	LC	-	-
Hoplestigmataceae	*Hoplestigma klaineanum*	4	-	-	-	NT	-	Endemic
Huaceae	*Afrostyrax kamerunensis*	-	1	-	-	LC	-	-
Huaceae	*Afrostyrax lepidophyllus*	-	73	-	-	LC	-	-
Humiriaceae	*Saccoglottis gabonensis*	6	-	-	-	LC	-	-
Hypericaceae	*Harungana madagascariensis*	-	-	-	-	LC	-	-
Irvingaceae	*Desbordesia glaucescens*	4	-	-	-	LC	-	-
Irvingaceae	*Irvingia gabonensis*	56	3	-	-	LC	-	-
Irvingaceae	*Irvingia grandifolia*	1	1	-	-	LC	-	-

Irvingaceae	*Klainedoxa gabonensis*	4	1	-	-	LC	-	-
Irvingaceae	*Klainedoxa trillesii*	7	-	-	-	LC	-	-
Lamiaceae	*Vitex grandifolia*	57	6	-	-	LC	-	-
Lamiaceae	*Vitex* sp.2	2	-	-	-	-	-	-
Lamiaceae	*Vitex* sp.3	33	-	-	-	-	-	-
Lamiaceae	*Vitex* sp.5	4	-	-	-	-	-	-
Lauraceae	*Beilschmiedia acuta*	4	2	-	-	DD	-	Endemic
Lauraceae	*Beilschmiedia gabonensis*	-	-	-	5	DD	-	Endemic
Lauraceae	*Beilschmiedia mannii*	7	3	-	-	LC	-	-
Lauraceae	*Beilschmiedia* sp.	11	1	-	-	-	-	-
Lauraceae	*Beilschmiedia* sp.2	4	13	-	-	-	-	-
Lauraceae	*Beilschmiedia* sp.22	-	-	-	1	-	-	-
Lauraceae	*Beilschmiedia* sp.6	29	33	-	-	-	-	-
Lauraceae	*Beilschmiedia talbotiae*	-	6	-	-	LC	-	-
Lauraceae	*Hypodaphnis zenkeri*	27	18	-	-	LC	-	-
Lauraceae	*Persea americana*	-	-	-	-	LC	-	-
Lecythidaceae	*Crateranthus talbotii*	114	-	-	-	VU	-	Endemic
Lecythidaceae	*Napoleonaea cf heudelotii*	7	66	-	-	-	-	-
Lecythidaceae	*Napoleonaea ergortonii*	-	-	-	-	VU	-	Endemic
Lecythidaceae	*Napoleonaea talbotii*	2	-	-	-	NT	-	Endemic
Lecythidaceae	*Oubanguia alata*	617	154	-	-	LC	-	-
Lecythidaceae	*Oubanguia laurifolia*	23	-	-	-	LC	-	-
Lecythidaceae	*Rhaptopetalum coriaceum*	5	-	-	-	NT	-	Endemic

Lecythidaceae	*Rhaptopetalum depressum*	-	-	-	-	CR	Endemic	-
Lecythidaceae	*Rhaptopetalum geophylax*	-	-	-	-	EN	Endemic	-
Lecythidaceae	*Rhaptopetalum* sp.	2	-	-	-	-	-	-
Lecythidaceae	*Rhaptopetalum sp.nov.*	11	1-	-	-	-	-	-
Lecythidaceae	*Scytopetalium klaineanum*	24	-	-	-	LC	-	-
Lepidobotryaceae	*Lepidobotrys staudtii*	2	-	-	-	LC	-	-
Leptaulaceae	*Leptaulus daphnoides*	6	-	1	-	LC	-	-
Leptaulaceae	*Leptaulus grandifolius*	-	-	-	-	VU	-	Endemic
Loganiaceae	*Strychnos congolana*	3	-	-	-	LC	-	-
Malvaceae	*Cola altissima*	1	-	-	-	LC	-	-
Malvaceae	*Cola cauliflora*	5	7	-	-	LC	-	Endemic
Malvaceae	*Cola chlamydantha*	4	-	-	-	LC	-	-
Malvaceae	*Cola flaviflora*	1	-	-	-	NT	-	Endemic
Malvaceae	*Cola lateritia*	5	-	-	-	LC	-	-
Malvaceae	*Cola lepidota*	24	8	-	-	LC	-	-
Malvaceae	*Cola megalophylla*	12	2	-	-	EN	-	Endemic
Malvaceae	*Cola nitida*	7	-	5	-	LC	-	-
Malvaceae	*Cola pachycarpa*	4	-	-	-	-	-	-
Malvaceae	*Cola rostrata*	74	5	-	-	LC	-	Endemic
Malvaceae	*Cola semecarpophylla*	-	1	-	-	LC	-	Endemic
Malvaceae	*Cola* sp.	2	-	-	-	-	-	-
Malvaceae	*Cola* sp.nov.	2	1	-	-	-	-	-
Malvaceae	*Cola verticillata*	24	2-	41	-	LC	-	-

Malvaceae	*Leptonychia lasiogyne*	-	-	-	-	LC	-	-
Malvaceae	*Leptonychia macrantha*	-	-	1	-	LC	-	-
Malvaceae	*Microcos coriacea*	18	8	-	-	LC	-	-
Malvaceae	*Octolobus spectabilis*	-	3	-	-	LC	-	-
Malvaceae	*Sterculia tragacantha*	7	6	-	-	LC	-	-
Melastomataceae	*Memecylon afzelii*	4	-	-	-	LC	-	-
Melastomataceae	*Memecylon candidum*	-	-	-	-	LC	-	-
Melastomataceae	*Memecylon lateriflorum*	1	8	-	-	-	-	-
Melastomataceae	*Memecylon laurentii*	-	1	-	-	LC	-	-
Melastomataceae	*Memecylon* sp.2	-	-	3	-	-	-	-
Melastomataceae	*Warneckea cinnamomoides*	6	-	-	-	LC	-	-
Melastomataceae	*Warneckea jasminoides*	9	2	-	-	LC	-	-
Melastomataceae	*Warneckea membranifolia*	2	-	-	-	LC	-	-
Melastomataceae	*Warneckea pulcherrima*	6	8	-	-	LC	-	-
Melastomataceae	*Warneckea* sp.I	1	-	-	-	-	-	-
Meliaceae	*Carapa angustifolia*	8	-	-	-	VU	-	Endemic
Meliaceae	*Carapa cf dinklagei*	-	-	-	-	NE	-	-
Meliaceae	*Carapa oreophila*	-	-	125	-	NT	-	Endemic
Meliaceae	*Carapa parviflora*	31	2	-	-	NE	-	-
Meliaceae	*Carapa zemagoana*	1	-	-	-	VU	Endemic	-
Meliaceae	*Entandrophragma cylindricum*	1	-	-	-	VU	-	-
Meliaceae	*Guarea cedrata*	1	-	11	-	VU	-	-
Meliaceae	*Guarea* sp.	-	-	-	-	-	-	-

Meliaceae	*Guarea thompsonii*	7	-	-	-	LC	-	-
Meliaceae	*Khaya ivorensis*	-	-	-	-	VU	-	-
Meliaceae	*Trichilia aff.gilgiana*	35	29	-	-	LC	-	-
Meliaceae	*Trichilia prieureana*	75	161	-	-	LC	-	-
Meliaceae	*Turraeanthus africanus*	-	-	-	-	LC	-	-
Melianthaceae	*Bersama abyssinica*	1	-	-	-	LC	-	-
Monimiaceae	*Glossocalyx brevipes* var letouzeyi	5	-	-	-	NT	Endemic	-
Moraceae	*Ficus mucuso*	-	1	-	-	LC	-	-
Moraceae	*Ficus* sp.	-	-	-	-	-	-	-
Moraceae	*Ficus* sp.3	12	4	-	-	-	-	-
Moraceae	*Ficus sur*	-	-	-	-	LC	-	-
Moraceae	*Milicia excelsa*	3	-	-	-	LC	-	-
Moraceae	*Treculia africana*	3	3	-	-	LC	-	-
Moraceae	*Treculia obovoidea*	13	-	-	-	LC	-	-
Myristicaceae	*Coelocaryon preussii*	33	13	-	-	LC	-	-
Myristicaceae	*Pycnanthus angolensis*	75	112	-	-	LC	-	-
Myristicaceae	*Scyphocephalium mannii*	43	9	-	-	LC	-	-
Myristicaceae	*Staudtia gabunensis*	35	1	-	-	LC	-	-
Myristicaceae	*Staudtia kamerunensis*	7	1	-	-	LC	-	-
Myristicaceae	*Staudtia* sp.	1	-	-	-	-	-	-
Myrsinaceae	*Maesa kamerunensis*	-	-	1	-	LC	-	-
Myrsinaceae	*Maesa lanceolata*	-	-	4	-	LC	-	-

Myrtaceae	*Eugenia callophyloides*	-	1	-	-	-	-	-
Myrtaceae	*Eugenia* sp.2	-	-	-	-	-	-	-
Myrtaceae	*Eugenia talbotii*	-	1	-	-	-	-	-
Myrtaceae	*Syzygium rowlandii*	2	1	14	-	LC	-	-
Myrtaceae	*Syzygium staudtii*	-	-	29	-	LC	-	-
Ochnaceae	*Campylospermum calanthum*	1	-	-	-	CR	Endemic	-
Ochnaceae	*Lophira alata*	7	-	-	-	VU	-	-
Ochnaceae	*Rhabdophyllum affine*	11	-	-	-	LC	-	-
Octoknemataceae	*Octoknema affinis*	65	43	-	-	LC	-	-
Octoknemataceae	*Octoknema anuwinlencis*	2	-	-	-	-	-	-
Octoknemataceae	*Octoknema bakosiensis*	59	-	-	-	EN	Endemic	-
Olacaceae	*Coula edulis*	45	-	-	-	LC	-	-
Olacaceae	*Diogoa* sp.	-	-	-	-	-	-	-
Olacaceae	*Diogoa zenkeri*	-	6	-	-	LC	-	-
Olacaceae	*Engomegoma gordonii*	2	-	-	-	LC	-	-
Olacaceae	*Strombosia grandifolia*	34	324	-	-	LC	-	-
Olacaceae	*Strombosia pustulata*	83	67	-	-	LC	-	-
Olacaceae	*Strombosia scheffleri*	45	62	-	-	LC	-	-
Olacaceae	*Strombosia* sp.	4	78	-	-	-	-	-
Olacaceae	*Strombosia* sp.1	-	-	146	-	-	-	-
Olacaceae	*Strombosiopsis tetrandra*	89	83	-	-	LC	-	-
Pandaceae	*Panda oleosa*	7	-	-	-	LC	-	-
Passifloraceae	*Barteria fistulosa*	23	11	-	-	LC	-	-

Peridiscaceae	*Soyauxia gabunensis*	121	23	-	-	VU	-	Endemic
Peridiscaceae	*Soyauxia talbotii*	-	-	-	-	VU	-	Endemic
Phyllanthaceae	*Antidesma chevaleri*	-	-	-	7	LC	-	-
Phyllanthaceae	*Antidesma laciniatum*	2	-	-	-	LC	-	-
Phyllanthaceae	*Antidesma* sp.	1	-	-	5	-	-	-
Phyllanthaceae	*Antidesma vogelianum*	27	19	-	-	LC	-	-
Phyllanthaceae	*Bridelia grandis*	3	1	12	-	LC	-	-
Phyllanthaceae	*Bridelia micrantha*	6	2	-	-	LC	-	-
Phyllanthaceae	*Keayodendron bridelioides*	3	-	-	-	LC	-	-
Phyllanthaceae	*Maesobotrya barteri*	5	-	-	-	LC	-	-
Phyllanthaceae	*Maesobotrya dusenii*	11	5	-	-	-	-	-
Phyllanthaceae	*Maesobotrya* sp.	-	-	-	-	-	-	-
Phyllanthaceae	*Maesobotrya staudtii*	3	4	-	-	LC	-	-
Phyllanthaceae	*Margaritaria discoidea*	2	6	-	-	LC	-	-
Phyllanthaceae	*Protomegabaria stapfiana*	275	54	-	-	LC	-	-
Phyllanthaceae	*Thecacoris leptobotrya*	2	-	-	-	LC	-	-
Phyllanthaceae	*Uapaca acuminata*	3	-	-	-	LC	-	-
Phyllanthaceae	*Uapaca guineensis*	1	-	-	-	LC	-	-
Phyllanthaceae	*Uapaca staudtii*	79	49	-	-	LC	-	-
Putranjivaceae	*Drypetes aframensis*	6	-	-	-	-	-	-
Putranjivaceae	*Drypetes afzelii*	-	2	-	-	-	-	-
Putranjivaceae	*Drypetes gossweileri*	-	14	-	-	-	-	-
Putranjivaceae	*Drypetes ivorensis*	2	1	-	-	-	-	-

Putranjivaceae	*Drypetes laciniata*	1	-	-	-	LC	-	-
Putranjivaceae	*Drypetes molunduana*	1	1	-	-	NT	-	-
Putranjivaceae	*Drypetes paxii*	1	1	-	-	LC	-	-
Putranjivaceae	*Drypetes* sp.3	-	-	-	-	-	-	-
Putranjivaceae	*Drypetes* sp.6	1	-	-	-	-	-	-
Putranjivaceae	*Drypetes* sp.7	-	-	37	-	-	-	-
Putranjivaceae	*Sibangea similis*	8	-	-	-	LC	-	-
Rhamnaceae	*Maesopsis eminii*	2	2	-	-	LC	-	-
Rubiaceae	*Aoranthe cladantha*	9	-	-	-	LC	-	-
Rubiaceae	*Aulacocalyx jasminiflora*	13	-	-	-	LC	-	-
Rubiaceae	*Aulacocalyx talbotii*	3	2	-	11	LC	-	-
Rubiaceae	*Bertiera racemosa*	2	-	-	-	LC	-	-
Rubiaceae	*Calycosiphonia spathicalyx*	1	-	-	-	LC	-	-
Rubiaceae	*Coffea* sp.	-	-	1	-	-	-	-
Rubiaceae	*Craterispermum aristatum*	21	-	-	-	VU	-	Endemic
Rubiaceae	*Cuviera subuliflora*	4	11	-	-	LC	-	-
Rubiaceae	*Hallea ledermannii*	4	-	-	-	-	-	-
Rubiaceae	*Heinsia crinita*	4	-	-	-	LC	-	-
Rubiaceae	*Ixora guineensis*	-	-	2	-	LC	-	-
Rubiaceae	*Morelia senegalensis*	2	-	-	-	LC	-	-
Rubiaceae	*Morinda lucida*	2	-	-	-	LC	-	-
Rubiaceae	*Nauclea diderrichii*	1	-	-	-	VU	-	-
Rubiaceae	*Nauclea* sp.	-	2	-	-	-	-	-

Rubiaceae	*Pauridiantha floribunda*	2	-	1	-	LC	-	-
Rubiaceae	*Pauridiantha* sp.	-	-	-	-	-	-	-
Rubiaceae	*Pauridiantha viridiflora*	3	3	-	-	LC	-	-
Rubiaceae	*Pausinystalia macroceras*	44	-	-	-	LC	-	-
Rubiaceae	*Pavetta staudtii*	-	-	-	-	LC	-	Endemic
Rubiaceae	*Petitiocodon parviflorum*	3	-	-	-	LC	-	Endemic
Rubiaceae	*Psychotria bimbiensis*	1	-	-	-	CR	Endemic	-
Rubiaceae	*Psychotria brachyantha*	-	-	1	-	LC	-	-
Rubiaceae	*Psychotria peduncularis*	-	-	-	-	LC	-	-
Rubiaceae	*Psychotria* sp.9	1	-	-	-	-	-	-
Rubiaceae	*Psydrax* sp.	-	-	-	-	-	-	-
Rubiaceae	*Rothmannia hispida*	1	1	-	-	LC	-	-
Rubiaceae	*Rothmannia* sp.	1	1	-	-	-	-	-
Rubiaceae	*Schumanniophyton magnificum*	-	5	2	-	LC	-	-
Rubiaceae	*Tarenna baconoides*	-	-	-	-	EN	-	Endemic
Rubiaceae	*Tarenna grandiflora*	6	-	-	-	LC	-	-
Rubiaceae	*Tricalysia amplexicaulis*	-	-	11	-	-	-	-
Rubiaceae	*Tricalysia coriacea*	-	2	-	-	LC	-	-
Ruscaceae	*Dracaena arborea*	-	-	-	-	LC	-	-
Ruscaceae	*Dracaena deisteliana*	2	-	-	-	NT	-	Endemic
Rutaceae	*Vepris adamaoua*	2	-	-	-	-	-	-
Rutaceae	*Vepris lecomteana*	-	-	49	-	NT	-	Endemic
Rutaceae	*Vepris soyauxii*	27	-	-	-	VU	-	Endemic

Rutaceae	*Vepris sp.*	-	-	-	-	-	-	-
Rutaceae	*Zanthoxylon gilletii*	27	44	-	-	LC	-	-
Rutaceae	*Zanthoxylon heitzii*	5	1	-	-	LC	-	-
Rutaceae	*Zanthoxylon lemairei*	-	-	2	-	LC	-	-
Rutaceae	*Zanthoxylon* sp.2	1	-	-	-	-	-	-
Rutaceae	*Zanthoxylon* sp.I	2	-	-	-	-	-	-
Salicaceae	*Casearia barteri*	2	2	-	-	LC	-	-
Salicaceae	*Homalium africanum*	36	6	-	-	LC	-	-
Salicaceae	*Homalium letestui*	27	-	-	-	LC	-	-
Salicaceae	*Homalium longistylum*	59	5	1	-	LC	-	-
Salicaceae	*Homalium macroptenum*	-	-	2	-	-	-	-
Salicaceae	*Homalium* sp.1	-	-	-	-	-	-	-
Salicaceae	*Oncoba glauca*	18	26	-	-	LC	-	-
Salicaceae	*Oncoba lophocarpa*	-	-	9	-	VU	Endemic	-
Salicaceae	*Oncoba mannii*	6	2	-	-	LC	-	-
Salicaceae	*Oncoba* sp.	-	-	1	-	-	-	-
Sapindaceae	*Allophylus africanus*	2	5	-	-	LC	-	-
Sapindaceae	*Allophylus grandifolius*	-	1	-	-	LC	-	-
Sapindaceae	*Allophylus* sp.2	-	-	1	-	-	-	-
Sapindaceae	*Allophylus* sp.3	-	-	-	4	-	-	-
Sapindaceae	*Blighia sapida*	6	2	-	-	LC	-	-
Sapindaceae	*Blighia welwitschii*	2	-	-	-	LC	-	-
Sapindaceae	*Chytranthus angustifolius*	1	-	-	-	LC	-	-

Sapindaceae	*Chytranthus talbotii*	-	1	-	-	LC	-	-
Sapindaceae	*Deinbollia pycnophylla*	5	5	-	-	EN	-	Endemic
Sapindaceae	*Eriocoelum kerstingii*	-	-	-	-	LC	-	-
Sapindaceae	*Eriocoelum macrocarpum*	29	47	-	-	LC	-	-
Sapindaceae	*Laccodiscus pseudostipularis*	-	2	-	-	LC	-	-
Sapindaceae	*Placodiscus cf. caudatus*	39	1	-	-	EN	-	Endemic
Sapotaceae	*cf Pradosia spinosa*	1	-	-	-	NE	-	-
Sapotaceae	*Englerophytum kennedyi*	3	-	-	-	-	-	-
Sapotaceae	*Englerophytum sp.nov.*	91	4	-	-	-	-	-
Sapotaceae	*Gambeya africanum*	27	-	-	-	LC	-	-
Sapotaceae	*Gambeya boukokoensis*	-	1	-	-	LC	-	-
Sapotaceae	*Gambeya delevoyi*	5	-	-	-	-	-	-
Sapotaceae	*Gambeya korupensis*	3	-	-	-	VU	Endemic	-
Sapotaceae	*Gambeya lacourtianum*	-	-	23	-	LC	-	-
Sapotaceae	*Gambeya subnudum*	5	8-	-	-	LC	-	-
Sapotaceae	*Lecomtedoxa klaineana*	4	-	-	-	VU	-	Endemic
Sapotaceae	*Manilkara argentea*	-	-	-	-	-	-	-
Sapotaceae	*Manilkara lososiana*	1	-	-	-	cr	Endemic	-
Sapotaceae	*Manilkara pellegriniana*	-	-	4	-	DD	-	-
Sapotaceae	*Omphalocarpum cf elatum*	12	-	-	-	LC	-	-
Sapotaceae	*Omphalocarpum elatum*	12	3	-	-	LC	-	-
Sapotaceae	*Pouteria* sp.	3	-	-	-	-	-	-
Sapotaceae	*Synsepalum letouzeyi*	-	-	-	-	EN	Endemic	-

Sapotaceae	*Synsepalum longecuneatum*	2	1	-	-	-	-	-
Simaroubaceae	*Odyendya gabonensis*	1	-	-	-	LC	-	-
Simaroubaceae	*Pierreodendron africanum*	14	1	-	-	LC	-	-
Simaroubaceae	*Quassia silvestris*	6	6	-	-	LC	-	-
Thymelaeaceae	*Dicranolepis pulcherrima*	-	-	1	-	LC	-	-
Ulmaceae	*Trema orientalis*	-	-	-	46	LC	-	-
Violaceae	*Alexis* cf *cauliflora*	2	-	-	-	LC	-	-
Violaceae	*Rinorea dentata*	1	1	-	-	LC	-	-
Violaceae	*Rinorea oblongifolia*	157	46	-	-	LC	-	-
Vochysiaceae	*Erismadelphus exsul*	8	8	-	-	LC	-	-
Vochysiaceae	*Korupiodendron songweanum*	164	-	-	-	EN	-	Endemic

Appendix 4.2. Summary table of distribution of biomass, and carbon Sequestered per hectare using Allometric models in four Tropical forest types in the Rumpi Hills Forest Reserve, Cameroon

Plot	Forest Types	AGB (t/ha)	Carbon (t/ha)
1	Lowland	328.8	164.4
2	Lowland	585.3	292.6
3	Lowland	456.4	228.4
4	Lowland	482.5	241.2
5	Lowland	375.0	187.5
6	Lowland	421.9	211.0
7	Lowland	412.5	206.2
8	Lowland	282.4	141.2
14	Lowland	253.1	126.6
15	Lowland	274.9	137.5
16	Lowland	386.6	193.3
17	Lowland	373.8	186.9
18	Mid-Elevation	260.1	130.1
19	Mid-Elevation	188.3	94.2
20	Mid-Elevation	261.5	130.8
21	Mid-Elevation	316.0	158.0
22	Mid-Elevation	238.9	119.5
23	Mid-Elevation	183.8	91.9
24	Mid-Elevation	309.2	154.6
25	Mid-Elevation	263.1	131.6
9	Submontane	317.4	158.6
10	Submontane	327.8	163.9
13	Submontane	129.1	64.6
11	Montane	362.0	181.0
12	Montane	353.5	176.8
Total		8,144.1	4,072.1
Mean		325.8	162.9
Standard deviation		100.8	50.4

CHAPTER FIVE

DIVERSITY, ABOVE-GROUND BIOMASS, AND VEGETATION PATTERNS IN THE TROPICAL DRY FOREST OF KIMBI-FUNGOM NATIONAL PARK, CAMEROON

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Preface

This chapter addresses the fourth objective of this study, which was to tackle the diversity, above ground biomass, and vegetation patterns in dry forest.

ABSTRACT

Considerable consensus exists regarding the importance of forests in carbon storage; however, the relationship between forest tree species composition and species richness and carbon Stock has not been fully established in the study area. The present study investigated the associations between above-ground biomass and species composition. The study further investigated how different vegetation types vary in terms of species composition, diversity, and carbon storage, in a dry forest in Kimbi-Fungom National Park, Cameroon. Vegetation was inventoried in 17 permanent 1-ha plots; using transects of 500 m long x 20 m wide. All trees and lianas with dbh ≥10 cm were measured with the aid of a diameter tape. In nested plots of 10x10 m, dbh ≤10 cm of trees and lianas were recorded with the help of a caliper. The multivariate analysis (TWINSPAN) revealed five vegetation types: semi-deciduous forest, secondary forest, mixed vegetation, gallery forest, and woody and grassland savanna. We found a mean of 269.8 tree stems ha^{-1} (range 157-404 tree stems ha^{-1}) and a mean of 43.1 species ha^{-1} (range 27-65 species ha^{-1}). The Shannon-Weiner diversity index was ≥2.5, with an average of 3.1, ranging 2.7-3.5. A total of 148 specimen vouchers were collected, including 144 species collected outside plot sampling; 116 species recorded during observational data did not occur in the different sample plots. Allometric equations were used to calculate above-ground biomass and carbon. The five vegetation types had an average above-ground biomass of 149.2 t ha^{-1} ranging 48.3-361.9 t ha^{-1}, and Carbon: 74.6 tC ha^{-1} (24.2-181 tC ha^{-1}) in the 17 ha analyzed. Correspondence analysis of data revealed two somewhat contrasting associations on the Axis 1: high elevation (846 – 898 m), low tree density, low above-ground biomass, low carbon and low species diversity were associated, whereas low elevation (396 – 481), high tree density, high species diversity, high carbon and high above-ground biomass showed weak correlations. All in all, the forests of the Kimbi-Fungom National Park were simultaneously poor in plant diversity and in both biomass and carbon, especially in the secondary, mixed vegetation, gallery, and grassland/woody savanna forest.

Key words: Dry forest, Bamenda Highlands, Kimbi-Fungom National Park, carbon, semi-deciduous, tree composition, diversity

5.1 INTRODUCTION

Globally, forest inventory and monitoring are key tools in understanding the structure, composition, diversity, above-ground biomass, and carbon storage of different vegetation types and habitats, and also serve as instruments by which to achieve targets for international agreements (UNEP/CBD, 2012). Dry forests are known to rank among the most threatened ecosystems globally, creating a need for detailed assessments of biodiversity hotspots, carbon stocks, and extent and preservation of these forests (Murphy and Lugo 1986; Janzen, 1988). Anthropogenic factors, such as land degradation, pastoral nomadism, and population expansion, are depleting dry forest extents, and natural factors like drought and fire also affect this biome. What is more, these ecosystems appear highly vulnerable even to small increases in temperature (UNFCCC, 2015).

Cameroon, situated at the juncture of West and Central Africa, holds important extents of Lower Guinean forest (White, 1983; Poorter et al., 2003), holding rich biodiversity totaling almost 9000 species, 1800 genera, and 230 families of vascular plants (Olivry, 1986; Onana, 2011; Onana, 2015). Cameroon holds three main biomes: dry savanna, moist savanna, and tropical rain forest. Dry savanna covers the northern parts of the country, and moist savanna and tropical rainforest form a mosaic across much of the rest of the country, except for montane areas. The dry savanna and moist semi-deciduous forest of Kimbi-Fungom National Park (KFNP) in the northwestern part of the country are assumed to be relatively species-poor, albeit with relatively few comparable studies (Sainge et al., 2014; Sainge, 2016). Indeed, fewer than 70 herbarium sheets, representing few than 60 plant species/100 km^2, have been collected from the KFNP area (Onana and Cheek, 2011; Onana, 2011; Onana, 2015). Although the vegetation of the Bamenda Highlands has been studied extensively (Cheek et al., 2000; Harvey et al., 2004; Cheek et al., 2010; T.F. Mbenkum and C.F Fisiy, pers. comm.), much remains to be understood regarding forest structure, species composition, species diversity, distribution, and carbon stocks across different vegetation types (Sainge et al., 2014; Sainge, 2016). Furthermore, few or no studies on carbon storage have been undertaken in dry forests in this region. Finally, the vegetation of the newly-established KFNP remains poorly understood; and since this park represents an important conservation effort in the region, a detailed understanding of its vegetation is paramount. Hence, this study aimed to understand patterns of plant species distribution and carbon storage across vegetation types, and their interrelationships in KFNP. Specific objectives were (i) to characterize forest structure; (ii) to characterize species composition, abundance, and distributions across vegetation types; and (iii) to estimate existing biomass and potential carbon storage.

5.2 Materials and Methods

5.2.1. Study Site

The study site lies within the Bamenda Highlands, in the North West Region of Cameroon, at latitude 6.5–6.9°N and longitude 9.8–10.5°E (Figure 1), covering 953.8 km^2. This forest is a mixture of humid semi-evergreen forest, woody savanna, grassland savanna, and gallery forest of the Sudano-Zambazien forest (Letouzey, 1985), with different habitats such as swampy *Pandanus* forest, *Raphia* forest, and inselberg. KFNP is the only national park in the Bamenda Highlands that is surrounded by other protected areas: Mt Oku, (peak at 3011 m), Mbembe Forest Reserve, Mt Tabenken, Nkom-Wum Forest Reserve, Mbi Crater, Kagwene Wildlife Sanctuary, Bali Ngemba Forest Reserve, and Bafut Ngemba Forest Reserve.

Plots were selected randomly and sampled, with 3-ha sampled in a dry semi-deciduous forest and the remaining 14-ha distributed in the dry forest of woody savanna, grassland savanna, gallery forest, swamp and secondary forest (Appendix 5A).

The climatic pattern in KFNP has two seasons within the Equatorial Cameroon climate type (Sainge, 2016), with dry season running November-mid March with < 100 mm for the season; December to February are the driest months. The rainy season occurs in April-October each year, with August and September the wettest months. No proper climatic data are available for this area; however, it is not expected to deviate much from the nearby Mbembe Forest, <100 km away, which has the following climatic conditions: rainfall (1824-1958 mm), temperature (21-24˚ C). Soils of KFNP forest are ferruginous, brown to gray in color (Yerima and Ranst 2005) and soil acidity of around pH 5.6. Plots were established at the central part, west of the national park at elevations of 429-898 m. During the study period, the woody and grassland savanna areas of the reserve were under intense cattle grazing, and the semi-deciduous forest was exposed to subsistence crop farming.

5.2.2 Field Sampling

We used line transects of 500 x 20 m as plots, established at irregular intervals in the various vegetation types. Each plot was divided into 25 quadrats of 20 x 20 m. We established 17 of these plots (425 quadrats), on which all trees and lianas ≥10 cm diameter at breast height (1.3 m, dbh) were sampled. Five 10 x 10 m quadrats within each 1 ha were selected at every 5th quadrat (i.e., quadrats 1, 6, 11, 16, and 21) where all trees and lianas of dbh <10 cm were measured, representing 0.05 ha sampled per hectare. Trees, shrubs, and lianas with dbh <10 cm were measured with calipers, whereas trees and lianas ≥10 cm were measured with a diameter tape. Lianas were measured above the last rooting points at a height of 1.3 m from the ground (Ewango, 2010; Ewango et al., 2015; Thomas et al., 2015). Tree height was determined as the average of visual estimates by 3 field staff base on an estimated guess. All sampled species were measured, and identified to morphospecies using field codes: voucher specimens were collected for all morphospecies. Dominant species were defined as species with the highest abundance of stems; rare species were those with only single stems for each vegetation type. Habitat type (swamp SW, flat dry forest FD, slope SL, plateau PL) was recorded for each plot. Finally, outside of plots sampled observational data were accumulated as we traversed the area to enhance the general species list for the area.

5.2.3 Data analysis

TWINSPAN multivariate analysis was used to classify vegetation types using the PC-ORD package (McCune and Mefford 2006). Species diversity estimates, correspondence analysis were achieved using PAST version 2.17 (Hammer et al., 2001). Correspondent analysis was carried out by converting data into binomials (0 and 1) and establishing relationship among elevation, species diversity, and carbon stock estimation using PAST version 2.17. Data for each vegetation type were separated into different life forms: trees ≥10 cm, shrubs ≤10 cm, and lianas ≥1 cm. Forest structure was classified into three strata (life forms): <10 m, 10-30 m (10-29 m), and ≥30 m height.

Above-ground biomass (AGB) was estimated for all trees with dbh ≥10 cm following the allometric equation of Chave et al., 2015 (equation 1). Tree height was estimated following Djomo et al., 2016 (equation 2):

$AGB = 0.0559(pD^2H)$ (Chave et al., 2015 equation 5)……….Eq. 1

$H = e^{1.321+0.482\ln D+0.027\ln p}$(Djomo et al., 2016)…………Eq. 2

AGB = Above-ground biomass (Tones), ρ = Wood specific density (g/cm^3) at 0% humidity
D (dbh) = diameter at breast height (1.30 m), *e* indicates the exponential function, H = Height in meters.
Carbon was estimated for trees ≥10 cm as

C = Total Biomass/2………………………………………………...Eq. 3

The forest structure and composition was described using phytosociological parameters such as basal area, relative density, relative dominance, relative frequency, and the important value index (Dallmeier, 1992).
Basal Area (BA) = Area occupied by plant (species) at breast height.

Basal area (BA) = $pi*(1/2dbh)^2 = pi*(dbh)^2/4$ ………..Eq. 4

Shannon-Weiner index (H') is the most convenient tool to measure diversity in 1-ha plots. This can be achieved through the following formula:

$H' = -\sum pi \ln pi$ …………..Eq. 5.

Where *pi* is the proportion of individual of a species (Number of individual of a species/total number of all species) and ln is the natural logarithm. Thus, the natural logarithm of the number of species (lnS) is the maximum value of H'.

5.3 RESULTS

5.3.1. Composition and Diversity

In total, 5551 stems of trees, shrubs, and lianas were recorded in 17 1-ha plots, dbh ≥1 cm. 4987 stems of trees and lianas, dbh ≥1 cm, belonging to 201 morphospecies with an average density of 293 stems ha^{-1} was recorded. However, 564 trees and lianas had multiple stems. In summary, 4607 tree, were recorded with dbh ≥10 cm, representing 178 species, 110 genera, and 42 families; 350 trees with dbh <10 cm representing 84 species, 72 genera, and 33 families, and 30 stems of lianas ≥1 cm (27 stems with dbh ≥10 cm and 3 stems with dbh <10 cm) representing 15 species, 15 genera, and 11 families (Table 5.1). In all, some 147 species (76.9%) were identified to the species level, as were 118 genera (83.6%). The mean number of trees ha^{-1} with dbh ≥10 cm in KFNP was 270±74 trees ha^{-1} (157-404 trees ha^{-1}). Shrubs with dbh <10 cm had an average of 135 trees ha^{-1}, with a range of 5-495 trees ha^{-1}. Lianas with dbh ≥1 cm had a mean of 2.8 stem ha^{-1}, with a range of 1-6 stems ha^{-1}.

Species richness and diversity varied among plots and life forms, with a mean of 43±13 species ha^{-1}, ranging from 27-65 species ha^{-1}. The Shannon-Weiner diversity index was ≥2.5, with an average of 3.1, ranging 2.7-3.5. A total of 148 specimen vouchers were collected, including 144 species collected outside plot sampling; 116 species recorded during observational data did not occur in the different sample plots (Appendix 5B).

5.3.2 Basal Area

The 17 ha plots gave a total basal area (dbh≥10 cm) of 257.4 m^2, with a mean of 15.1 m^2 ha^{-1} (range 6.8-32.4 m^2 ha^{-1}). The dominant family was Fabaceae (87.0 m^2, 33.2%; Table 2), followed by Chrysobalanaceae (27.3 m^2), >Phyllanthaceae (21.6 m^2), >Anacardiaceae (19.0 m^2), >Combretaceae (11.0 m^2). Dominant genera were *Brachystegia* (31.4 m^2), *Maranthes* (26.3 m^2), *Uapaca* (17.7 m^2), *Daniellia* (17.1 m^2), *Pseudospondias* (11.3 m^2) and *Terminalia* (10.3 m^2) (Table 5.3). Dominant species were *Brachystegia eurycoma*, *Maranthes glabra*, *Daniellia oliveri*, *Uapaca togoensis*, *Pseudospondias microcarpa* and *Terminalia glaucescens*. The total basal area for trees <10 cm dbh was 1.7 m^2 ha^{-1} whereas lianas gave 3.6 m^2 ha^{-1}. Semi-deciduous forest had the largest basal area (Table 5.4).

5.3.3 Forest Structure

Tree height within the five vegetation types ranged 2–45 m. The 17 ha plots resulted in 4607 trees of 178 species, 110 genera, and 42 families in morphospecies for trees ≥10 cm dbh. Trees <10 m tall formed the bulk of abundance, representing 66.6% (3068 tree stems), >10 m (10-29 m) was 29.0% (1336 tree stems), and ≥30 m gave 4.1% (190 stems). At the vegetation level, for trees <10 m, gallery forest represented 6.6% (201 stems), woody and grassland savanna 66.2% (2029 stems), mixed vegetation 2.1% (63 stems), semi-deciduous forest 19.8% (606 stems), and secondary forest 5.5% (169 stems; Tables 5.5).

5.3.4 Classification and Vegetation Patterns

Multivariate analyses using TWINSPAN revealed five vegetation types, dry semi-deciduous forest, here termed primary forest and four dry forest types (secondary forest, gallery forest, mixed vegetation, grassland/woody savanna) in Cameroon (Figure 5.2), with 4607 stems in 178 morphospecies, 110 genera, and 42 families. Twenty-one and twelve individuals were not identified to genus and family, respectively. Main and secondary forest matrices were based on abundances of tree species ≥10 cm that were all identified to species, measured for dbh, and with data on elevation (Figures 5.2 & 5.3). The floristic canonical correspondence analysis (CCA) reveals great variation within the different vegetation type with an eigenvalue of 0.8 expressed toward axis 2 and 0.2 expressed toward axis 1 along elevational gradient (Figure 5.3).

In all, 7 plots had elements of semi-deciduous forest representing 4.52 ha with a total of 1559 stems in 130 species, 89 genera, and 39 families. Dominant species were *Maranthes glabra*, with 227 stems, *Sorindeia grandifolia* (95 stems), *Spondianthus preussii* (93 stems), *Pseudospondias microcarpa* (85 stems), *Chrysophyllum ubanguiense* (75 stems), and *Brachystegia eurycoma* (70 stems). In this vegetation type, 37 species were rare, with one individual each, such as *Beilschmiedia gabonensis*, *Bridelia atroviridis*, *Daniellia oliveri*, *Englerophytum stelechanthum*, and *Shirakiopsis elliptica*.

Secondary forest (three plots) representing 0.96 ha, had 259 stems pertaining to 55 species, 44 genera, and 26 families. One morphospecies was identified only to genus and one only to family. Dominant species were *Hallea stipulosa* (36 stems), *Ricinodendron heudelotii* (18 stems), *Albizia zygia* (17 stems), *Trema orientalis* (12 stems), and *Anthocleista djalonensis*, and *Sterculia tragacantha* with 10 stems each. Eighteen species were rare in this vegetation type, with one individual each, such as *Alstonia boonei* , *Daniellia oliveri* , *Erythrophleum suaveolens* , *Irvingia wombulu* , and *Quassia sylvestris* .

Gallery forest found in 8 plots representing 0.8 ha, had a total of 276 stems belonging to 53 species, 44 genera, and 24 families. Dominant species were *Uapaca togoensis* (96 stems), *Daniellia oliveri* (20 stems), *Vitex doniana* (13 stems), and *Hymenocardia acida* (11 stems); 19 rare species included *Afzelia africana*., *Albizia adianthifolia*, *Cassia arereh*, *Cola cordifolia* and *Pterocarpus erinaceus*.

Mixed vegetation (4 plots) representing 0.4 ha, had 129 stems belonging to 37 species, 31 genera, and 21 families, with 2 morphospecies not identified to genus or family. Dominant species were *Uapaca togoensis* (20 stems), *Maranthes glabra* (15 stems), *Vitex doniana* (9 stems), and *Nauclea latifolia* (8 stems); 16 rare species included *Annona senegalensis*., *Beilschmiedia anacardioides*, *Brachystegia eurycoma*, *Elaeis guineensis*., and *Vitex rivularis*.

Grassland/woody savanna (14 plots) representing 10.12 ha, had a total of 2383 stems belonging to 77 species, 55 genera, and 29 families (3 morphospecies were not identified to genus, 28 morphospecies were not identified to family). Dominant species in this vegetation type were *Hymenocardia acida* (237 stems), *Terminalia glaucescens* (231), *Crossopteryx febrifuga, Nauclea latifolia* (225 stems), *Lophira lanceolata* (186 stems), *Daniellia oliveri* (147 stems), *Entada abyssinica* (116 stems), *Piliostigma thonningii* (111 stems), *Cussonia arborea* (105 stems), and *Uapaca togoensis* (86 stems). Rare species totaled 21, including *Albizia adianthifolia*, *Antidesma chevalieri, Erythrina senegalensis Maesopsis eminii*., *Magnistipula butayei*, *Milicia excelsa*, *Morelia senegalensis*, *Pterocarpus erinaceus*, and *Uapaca paludosa* (Table 4). Five quadrats were empty in the entire study representing 0.2 ha. In all, 16.8 ha were fully sampled. At an elevation of 396-481, high values of number of species, tree density, and above-ground biomass was experiences with an eigenvalue of 65% at axis 1 while at 845-1000, low number of species, tree density, and above-ground biomass was recorded with at eigenvalue of 17% at axis 2 (Figure 5.4 a & b).

5.3.5 Above-Ground Biomass and Carbon

The 17 ha of sampled plots in KFNP yielded a total above-ground biomass of 2537.3 t, and carbon of 1268.6 t (Appendix 5C). Among the 11 families with highest above-ground biomass (AGB), Fabaceae had the highest AGB (914.9 t ha^{-1}), corresponding to 457.5 t ha^{-1} of carbon (Table 5.2). *Brachystegia eurycoma* recorded the highest AGB of any species (439.3 t ha^{-1}) equivalent to 219.6 t ha^{-1} of carbon (Table 5.3). Mean AGB by vegetation type was 203.8 t ha^{-1} in mixed vegetation forest, 72 t ha^{-1} in grassland/woody savanna, 141 t ha^{-1} in gallery forest, 167.7 t ha^{-1} in secondary forest, and 321.5 t ha^{-1} in semi-deciduous forest (Table 5.4). The correspondence analysis shows that the first two axes accounted for 82% (axis 1 = 65% and axis 2 = 17%) of total variation in this study. Correspondence analysis of data revealed two somewhat contrasting associations on the Axis 1: high elevation (846 – 898 m), low tree density, low above-ground biomass and low species diversity were associated, whereas low elevation (396 – 481), high tree density, high species diversity and high above-ground biomass showed weakly correlations. An overall species list and abundance in the 17 1-ha permanent plots were represented in appendix 5D.

5.4 DISCUSSION

Tree diversity, density, and diameter are important indicators in assessing forest carbon and other ecological processes in tropical forests. However, these indicators vary across regions, vegetation types, and habitats. Generally, average tree density in the dry forest of KFNP was lower compared to similar tropical dry forests in other regions: for example mean tree densities of 994 stems ha^{-1} (dbh > 10 cm) and 3486 stems ha^{-1} (dbh > 1 cm) were documented in the tropical dry forest of Bannerghatta National Park of the Eastern Ghats in southern India and Hawaiian lowland dry forest, respectively (Ostertag et al., 2014; Gopalakrishna et al., 2015). A similar study in nearby Mbembe Forest Reserve at different vegetation types, gave an average of 741 stems ha^{-1} in woody savanna, 236 stems ha^{-1} in grassland savanna and 4963 stems ha^{-1} in semi-deciduous forest at dbh≥ 1 cm (Sainge et al., 2014). Trees with dbh≥ 10 cm in the Mbembe forest gave an average of 311 stems ha^{-1} in woody savanna, 124 stems ha^{-1} in grassland savanna and 408 stems ha^{-1} in semi-deciduous forest (Sainge et al., 2014). The low tree density in KFNP and indeed in the greater Bamenda Highlands could be attributed to unsustainable practices such as gathering of fuel wood, timber exploitation, pastoral nomadism, and subsistence agriculture. The tree species that were most affected were *Afzelia africana, Daniella oliveri, Erythrophleum suaveolens, Hymenocardia acida, Terminalia glaucescens* (Sainge et al., 2014; Sainge, 2016). Nevertheless, globally, tropical dry forests are highly threatened: recent reports are that tropical dry forests in Latin America and the Caribbean have been reduced to <10% of their original extent (Banda et al., 2016). The current results highlight the poor state of KFNP and the need for appropriate interventions. It worth-mentioning that this is one of the few studies in Cameroon and the Congo Basin sub-region that looks at diversity, above-ground biomass and carbon in a dry forest (Sainge et al., 2012; Sainge et al., 2014; Ekoungoulou et al., 2014; Sainge, 2016).

Mean tree species richness (for trees with dbh ≥10 cm) of 43.1±13.3 species ha^{-1} (27-65 species ha^{-1}) in KFNP were comparable to those obtained in the dry forest of the Western Ghats, in Milodai & Courtallam Forest Reserve, India, which ranged from 30-57 species ha^{-1} (Chandrashekara and Ramakrishna 1994; Parthasarathy and Karthikeyan 1997). Studies of mature tropical forests revealed a minimum value for species richness for trees with dbh ≥10 cm of 56 species (Philips and Gentry 1994). However, mean tree species richness of 43.1 species ha^{-1} (27-65 species ha^{-1}) in KFNP, in comparison to rainforests of Rumpi Hills (lowland forest 117.5 species ha^{-1}, and submontane 75 species ha^{-1}), and Korup National Park (88.5 species ha^{-1}), is lowland (Newbery and Gartlan 1996; Thomas et al., 2003; Chuyong et al., 2004; Kenfack et al., 2007; Gonmadje et al., 2011). Thus, KFNP with a mean of 43.1 species ha^{-1} and Mbembe forest 29.75 species ha^{-1} can be considered as quite species-poor. Species richness and diversity in KFNP shows results similar to nearby Mbembe Forest Reserve with a Shannon index of ≥ 3 (Sainge et al., 2014).

In this study, the number of species and basal area was higher in dry semi-deciduous forest than in the other vegetation types (Table 5.4). This is evident, since semi-deciduous forest is more closed to lowland or mid-elevation rainforest with large trees, dense with fewer gaps than the open grassland/woody savanna that is prone to fire annually. The most abundant families were Fabaceae with 887 individual trees, Rubiaceae (783 trees) and Phyllanthaceae (503 trees) (Table 5.2), while the most abundance species were *Terminalia glaucescens* (271 trees), *Maranthes glabra* (Oliv.) (263 trees), and *Uapaca togoensis* (256 trees, Table 5.3). Ten species in our study yielded 1618.8 t of above-ground biomass (63.8%) of the total AGB (2537.3 t) with an overall abundance of 1489 tree stems (Table 5.3), suggesting that biomass is relatively dependent to tree diameter.

In the 17 ha sampled, we calculated a mean AGB of 149.2 t ha^{-1} (48.3-361.9 t ha^{-1}), and carbon 74.6 tC ha^{-1} (24.2-181 tC ha^{-1}). These values are far lower compared to the minimum values of AGB (429 t ha^{-1}) and carbon stock estimate of 249 tC ha^{-1} documented previously for Central African forests (Lewis et al., 2013). Although the present study revealed KFNP is poor in mean AGB and carbon, exceptions were observed for some specific plots: for example, plots 1-3 had high mean AGB of 356.3 t ha^{-1} (346.8-361.9 t ha^{-1}), a mean carbon of 178.2 tC ha^{-1} (173.4-181 tC/ha), which is only slightly lower than values documented by Lewis et al. 2013 (Appendix C). In Congo Brazzaville (Iboukikro and Ngambali Forest), a study conducted by Ekoungoulou et al. (2014) in 6 1-ha plots in a gallery forest revealed a mean of 170.7 tC ha^{-1} (99.6-223.2 tC ha^{-1}), which is still higher than that of the gallery forest in KFNP (70.5 tC ha^{-1}), in which the ten most abundant species showed high density overall and per vegetation type when compared to the general and respective totals (Table 5.6).

We noted a close association among variables: low tree density, low above-ground biomass, low species diversity and high altitude in KFNP; conversely, high tree density, high species diversity and high above-ground biomass were linked. Low carbon was closely associated with low tree density, low species diversity, and high altitude as opposed to high carbon, high tree density, high species diversity at low altitude. The semi-deciduous forest recorded the highest AGB and number of species, and mixed vegetation the lowest AGB (Table 5.4). Although previous studies of the relationship between species richness and carbon storage have yielded mixed results, most studies have found a positive association between species richness and above-ground productivity (Thompson et al., 2009; Strassburg et al., 2010). Whereas the low carbon content in the grassland/woody savanna, gallery, and mixed forest may be attributed to the open vegetation, and anthropogenic activities, other factors such as rainfall, duration of wet season, and topography can also influence net primary productivity of tropical dry forest (Murphy and Lugo1986).

In conclusion, this study demonstrated a positive association between above-ground biomass and number of species per hectare. The current study revealed that the forest of the Kimbi-Fungom National Park is simultaneously poor in plant diversity, biomass, and carbon.

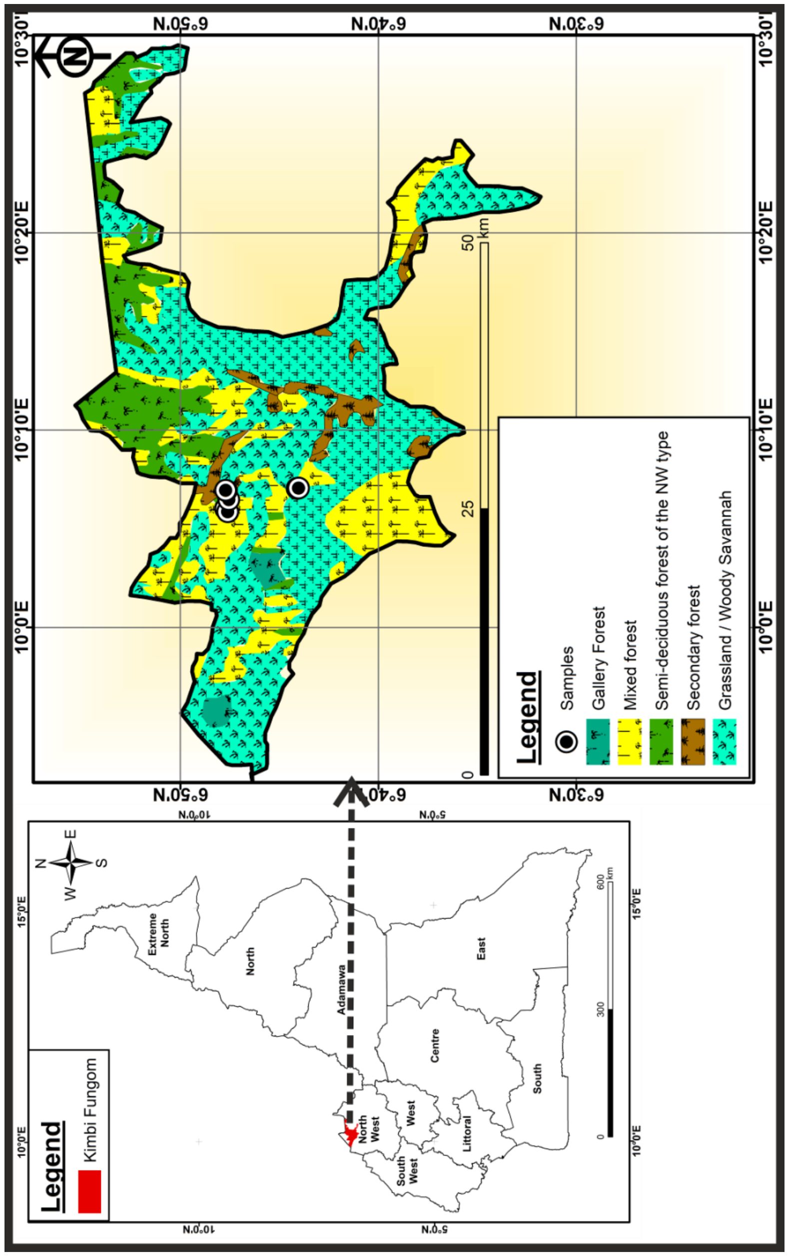

Figure 5.1. Vegetation types and sample locations across the Kimbi-Fungom National Park, Cameroon.

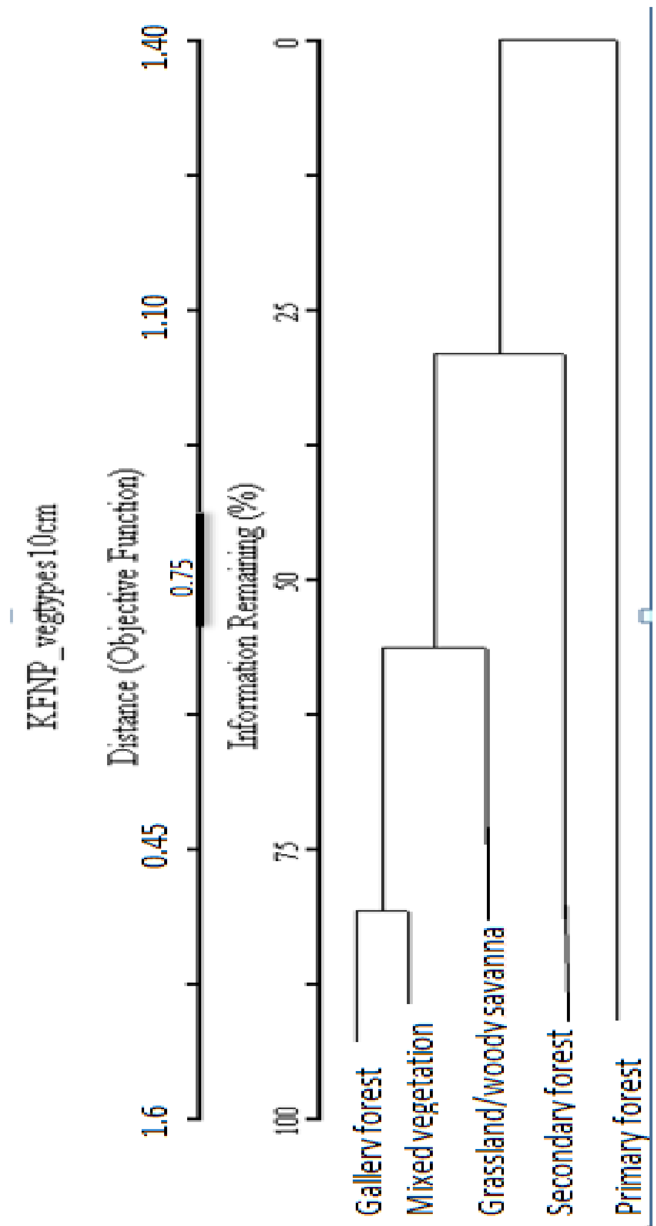

Figure 5.2. TWINSPAN dendrogram of 120 species of vascular plants with dbh ≥10 cm in 17 plots of 1-ha each in the Kimbi-Fungom National Park, Cameroon.

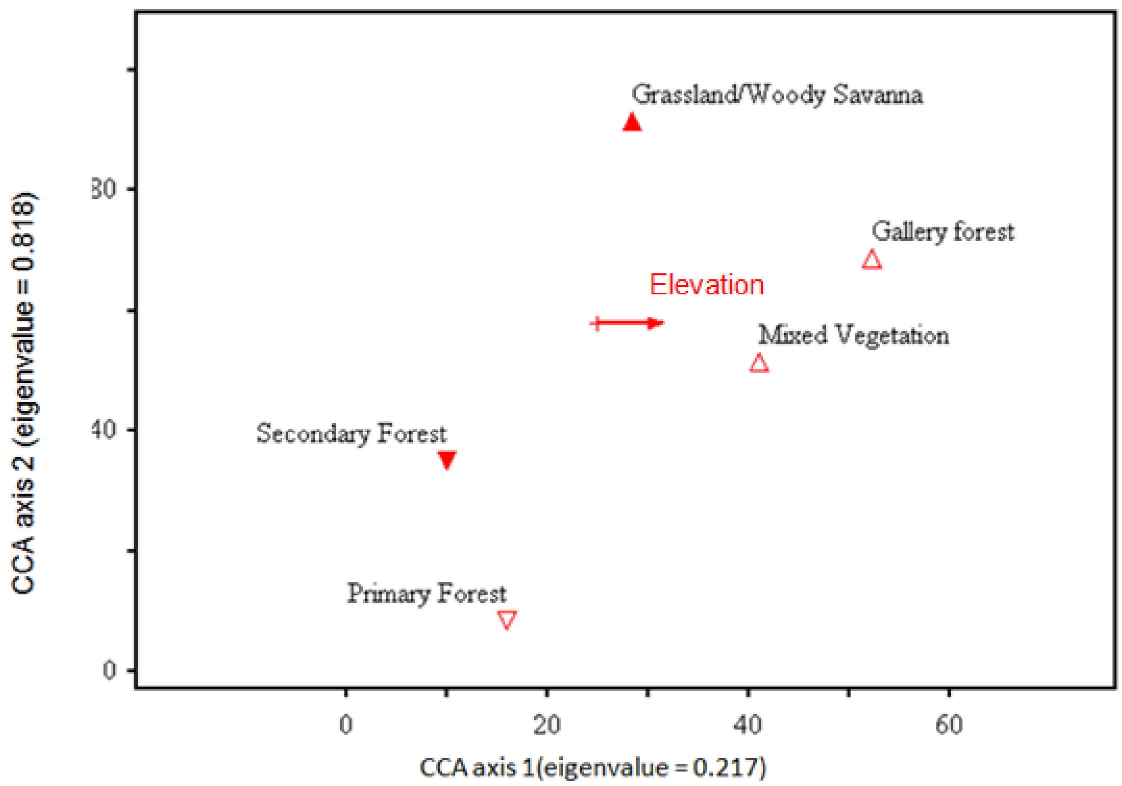

Figure 5.3. Floristic Canonical Correspondence Analysis (CCA) with 17 1-ha sample plots and 5 vegetation types from TWINSPAN analysis in the Kimbi-Fungom National Park, Cameroon.

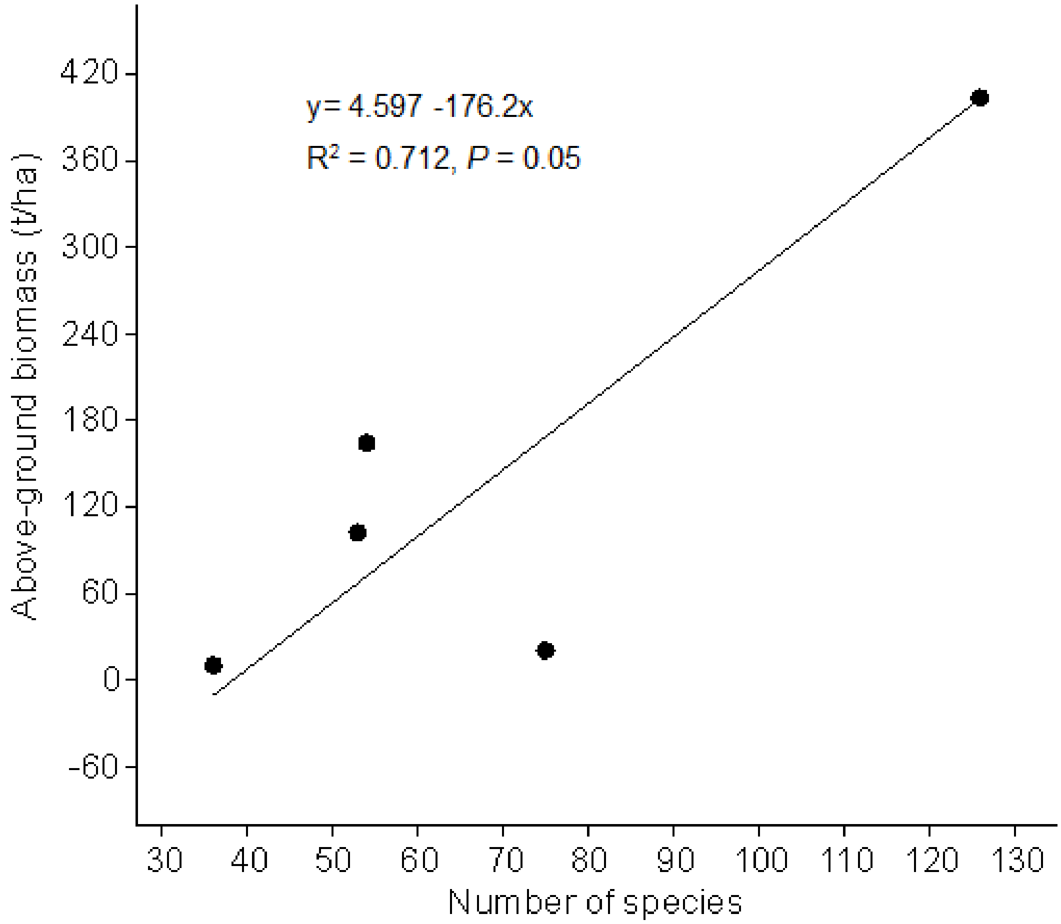

Figure 5.4. Association between above-ground biomass and numbers of species of trees of dbh ≥10 cm recorded in 17 1-ha plots at the Kimbi-Fungom National Park, Cameroon.

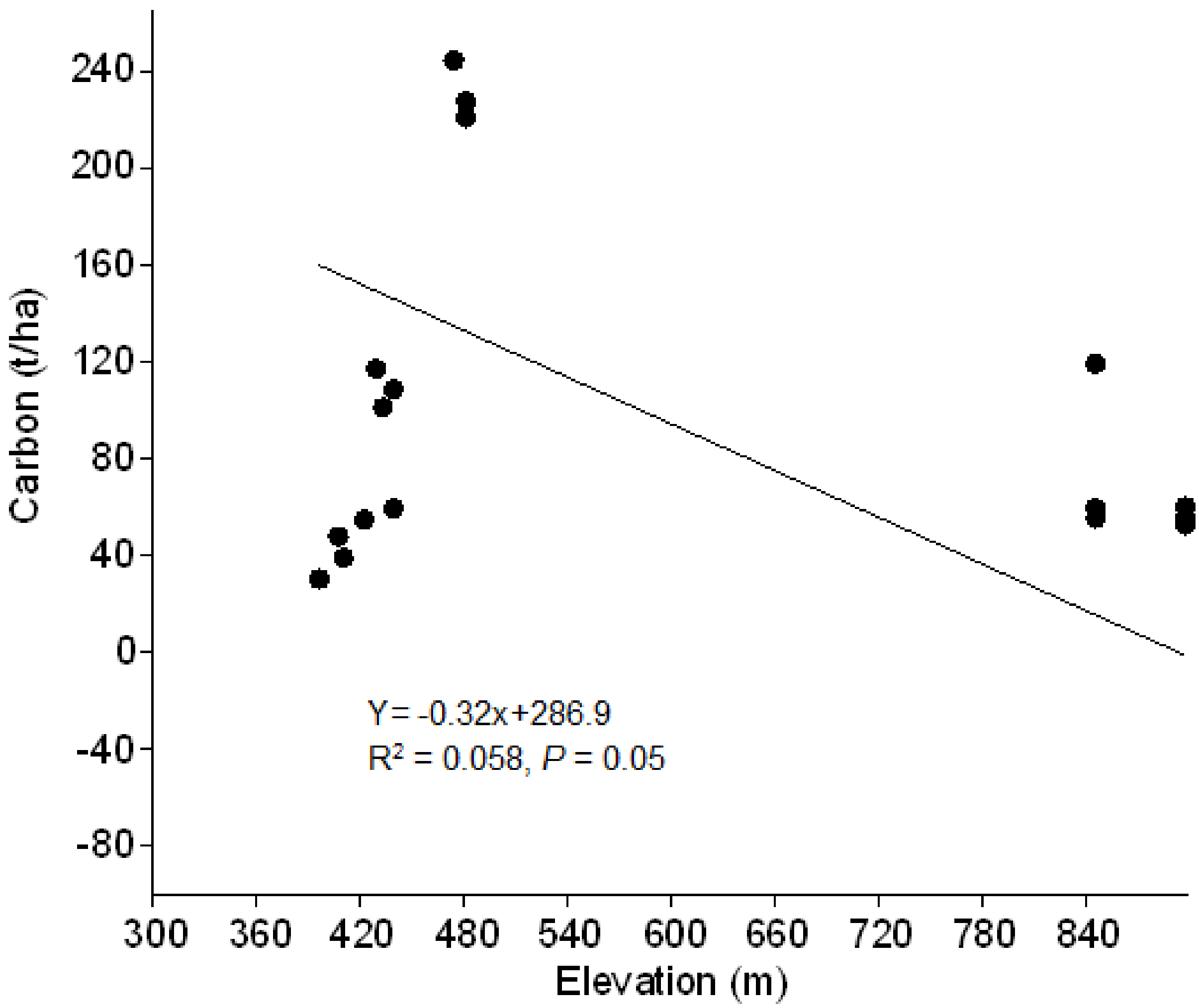

Figure 5.5 Weak association (R^2= 0.0594, P<0.05) between carbon and elevation across different plots for tree species of dbh ≥10 cm recorded in 17 1-ha plots at the Kimbi-Fungom National Park, Cameroon.

Table 5.1. Different vegetation cover types and corresponding numbers of species, stems, and mean Shannon diversity index in Kimbi-Fungom National Park forest, Cameroon

Vegetation cover	No. of species	No. of stems	dbh	Mean Shannon diversity index
shrubs	84	350	≤ 10 cm	1.8 (0-3.4)
lianas	10	25	≥ 1cm	0.26 (0.6-1.8)
trees	178	4607	≥ 10 cm	3.12 (2.6-3.5)

Table 5.2. Eleven plant families in terms of highest above ground biomass, and carbon stock in the Kimbi-Fungom National Park, Cameroon

Family	Biomass (t/ha)	Carbon (t/ha)	BA (m^2/ha)	Abundance
Fabaceae	1271.68	635.84	83.30	1010
Chrysobalanaceae	403.68	201.84	27.15	278
Anacardiaceae	241.56	120.78	18.56	320
Phyllanthaceae	204.57	102.28	19.65	431
Euphorbiaceae	118.11	59.05	9.03	156
Combretaceae	106.84	53.42	10.25	263
Myristicaceae	94.71	47.36	5.73	40
Moraceae	91.11	45.56	7.27	177
Ochnaceae	82.74	41.37	8.87	211
Arecaceae	71.93	35.97	5.50	49
Rubiaceae	62.07	31.03	7.65	388

Table 5.3. Ten species with highest above-ground biomass, and carbon in 17 1-ha plots in Kimbi-Fungom National Park, Cameroon.

Species	Biomass (t/ha)	Carbon (t/ha)	Basal Area (m^2/ha)	Abundance
Brachystegia eurycoma Harms	635.97	317.98	31.37	77
Maranthes glabra (Oliv.) G.T. Prance	393.03	196.52	26.20	260
Daniellia oliveri (Rolfe) Hutch. & Dalziel	236.74	118.37	16.88	170
Pseudospondias microcarpa (A.Rich.) Engl.	164.93	82.46	11.19	97
Erythrophleum suaveolens (Guill. & Perr.) Brenan	117.90	58.95	7.48	50
Uapaca togoensis Pax	112.01	56.00	10.79	213
Terminalia glaucescens Planch.ex Benth.	99.54	49.77	9.53	242
Pycnanthus angolensis (Welw.) Exell	94.71	47.36	5.73	40
Ricinodendron heudelotii (Baill.) Pierre ex Baill.	93.32	46.66	6.08	43
Lophira lanceolata Tiegh. Ex Keay	80.54	40.27	8.57	198

Table 5.4. Mean above-ground biomass, carbon, basal area, and species richness, across five vegetation types in Kimbi-Fungom National Park, Cameroon.

Vegetation Types	Biomass (t/ha)	Carbon (t/ha)	Basal Area (m^2)	Number of Species
Semi-deciduous forest	403.6	201.8	27.7	126
Secondary forest	164.2	82.1	12.9	54
Grassland/woody savanna	20.5	10.3	1.6	75
Mixed vegetation	10.3	5.1	0.8	36
Gallery forest	102.1	51.1	7.7	53

Table 5.5. Vegetation types and corresponding mean tree height (in m; range in parentheses) in sample plots in Kimbi-Fungom National Park, Cameroon.

Vegetation types	Mean tree height (range)
Semi-deciduous forest	21.6 (2-45)
Secondary forest	15 (4-45)
Grassland/woody savanna	12.2 (2-25)
Mixed vegetation	15.1 (4-34)

Appendix 5.1. Sampling plot locations, number of species/ha and individual trees/ha in the Kimbi-Fungom National Park, Cameroon

Plot	Vegetation type	Site	Location	Latitude (N)	Longitude (S)	Elevation (m)
1	PSF	KFNP	Kpep	6.79533	10.10048	481
2	PSF	KFNP	Kpep	6.79533	10.10048	481
3	PSF	KFNP	Kpep	6.79528	10.10029	474
4	GS_MV_PSF	KFNP	Kpep	6.79339	10.09769	429
5	PSF_GS	KFNP	Kpep	6.79359	10.09773	433
6	GS_GAL_SF	KFNP	Kpep	6.79267	10.10803	439
7	GS_GAL_SF	KFNP	Kpep	6.79267	10.10803	439
8	WS_MV_GAL	KFNP	Kpep	6.79502	10.11571	396
9	WS	KFNP	Kpep	6.79484	10.11546	407
10	WS_PSF	KFNP	Kpep	6.79516	10.11585	410
11	SF_GAL_WS	KFNP	Kpep	6.79534	10.11585	422
12	GS_GAL	KFNP	Tunka-Esu	6.73506	10.11741	898
13	GS_GAL	KFNP	Tunka-Esu	6.73506	10.11741	898
14	GS	KFNP	Tunka-Esu	6.73506	10.11741	898
15	GS_GAL	KFNP	Tunka-Esu	6.73394	10.11772	846
16	GS_MV	KFNP	Tunka-Esu	6.73394	10.11772	846
17	GS_PSF	KFNP	Tunka-Esu	6.73394	10.11772	846

GF=Gallery forest, G/WS=Grassland/Woody savanna, MV=Mixed vegetation, PSF=Primary Semi-deciduous Forest, SF=Secondary Forest

Appendix 5.2 Plant species recorded in observational efforts (i.e., outside of sampling plots) in the Kimbi-Fungom National Park, Cameroon.

Family	Species
Acanthaceae	*Acanthus montanus* (Nees) T.Anderson
Acanthaceae	*Asystasia decipiens* Heine
Amaranthaceae	*Amaranthus* sp.
Anacardiaceae	*Lannea kerstingii* Engl. & K. Krauce
Annonaceae	*Artabotrys aurantiacus* Engl. & Diels.
Annonaceae	*Uvaria* sp.
Annonaceae	*Xylopia* sp.
Apocynaceae	*Baissea axillaris* (Benth.) Hua
Apocynaceae	*Landolphia* sp.
Asclepiadaceae	*Marsdenia* sp.
Asparagaceae	*Asparagus flagellaris*
Asparagaceae	*Chlorophytum macrophyllum* (A.Rich.) Aschers.
Asteraceae	*Chromolaena odorata* (L.) R.M.King & H.Robinson (nat.)
Asteraceae	*Vernonia kotschyana* Sch. Bip.
Bignoniaceae	*Crescentia cujute* Billb. & Beurl. (exo.)
Chrysobalanaceae	*Dactyladenia barteri* (Hook.f.ex Oliv.) G.T. Prance & F. White
Chrysobalanaceae	*Magnistipula cuneatifolia* Hauman
Clusiaceae	*Garcinia* cf *barteri*
Colchicaceae	*Gloriosa simplex*
Combretaceae	*Agelaea pseudobliqua*
Commeliniaceae	*Palisota ambigua* (P.Beauv.) C.B. Clarke
Connaraceae	Connarus griffonianus Baill.
Connaraceae	*Jaundea pubescens*
Costaceae	*Costus spectabilis* (Fenzl) K. Schum.
Dichapetalaceae	*Dichapetalum* sp.
Dilleniaceae	*Tetracera masuiana* De Wild. & T. Durand
Dilleniaceae	*Tetracera* sp.
Dioscoreaceae	*Dioscorea alata* L.
Ebenaceae	*Diospyros monbuttensis* Gürke
Euphorbiaceae	*Shirakiopsis elliptica* (Hochst.) Esser
Fabaceae	*Albizia adianthifolia* (Shum.) W.F. Wright
Fabaceae	*Anthonotha macrophylla* P. Beauv.
Fabaceae	*Crotalaria macrocalyx* Benth.
Fabaceae	*Dalbergia* sp.
Fabaceae	*Dalbergiella welwitschii* Baker
Fabaceae	*Desmodium hirtum* Guill. & Perr.

Fabaceae	*Desmodium velutinum* (Wild.) DC.
Fabaceae	*Dialium zenkeri* Harms
Fabaceae	*Oddoniodendron micranthum* (Harms) Baker
Fabaceae	*Pseudarthria hookeri* Wright & Arn.
Fabaceae	*Sesbania* sp.
Fabaceae	*Tamarindus indica* Linn.
Fabaceae	*Tephrosia barbigera* Welw.ex Bak.
Gentianaceae	*Anthocleista liebrechtsiana* De Wild
Hypericaceae	*Psorospermum glaucum*
Hypericaceae	*Psorospermum* sp.
Hypericaceae	*Psorospermum* sp.3
Lamiaceae	*Lippia africana*
Lamiaceae	*Solamestemum latifolius*
Lamiaceae	*Vitex myrmecophila*
Lamiaceae	*Vitex thyrsifolia* Baker
Leeaceae	*Leea guineensis* G.Don
Loganiaceae	*Strychnos spinosa* Lam.
Loganiaceae	*Strychnos tricalysioides* Hutch. & M.B.Moss
Malvaceae	*Cola millenii* K. Schum.
Malvaceae	*Microcos mollis* Juss.
Malvaceae	*Sida corymbosa*
Malvaceae	*Sterculia setigera* Delile
Marantaceae	*Megaphrynium macrostachyum* (Benth.) Milne-Redh.
Melastomataceae	*Dissotis brazzae* Cogn.
Moraceae	*Ficus craterostoma* Mildbr. & Burret
Musaceae	*Ensete livingstonianum* (J.Kirk) Cheesman
Myristicaceae	*Coelocaryon botryoides* Verm.
Myrtaceae	*Eugenia obanensis* Baker.f.
Ochnaceae	*Campylospermum calanthum* (Gilg.) Farron
Ochnaceae	*Campylospermum excavatum* (Van Tiegh.) Farron
Ochnaceae	*Campylospermum flavum* (Schum. & Thonn.) Farron
Ochnaceae	*Rhabdophyllum affine* (Hook.f.) Van Tiegh.
Olacaceae	*Strombosia grandifolia* Hook.f.
Orchidaceae	*Ancistrochilus rothschildianus* O'Brien
Orchidaceae	*Ancistrorhynchus serratus* Summerh
Orchidaceae	*Bulbophyllum colubrinum* (Rchb.f.) Rchb.f.
Orchidaceae	*Bulbophyllum vuleanicum*
Orchidaceae	*Eulophia euglossa* (Rchb.f.) Rolfe
Orchidaceae	*Habenaria longinostris*
Orchidaceae	*Habenaria longirostris* Summerhayes
Orchidaceae	*Habenaria malacophylla* Rchb.f.

Orchidaceae	*Liparis caillei* Finet
Orchidaceae	*Liparis guineensis*
Orchidaceae	*Nervilia* sp.
Orchidaceae	*Polystachya odorata* Lindl.
Orchidaceae	*Vanilla imperialis* Kraenzl.
Passifloraceae	*Adenia cissampeloides* (Planch.ex Hook.) Harms
Passifloraceae	*Adenia* sp.1
Petiveriaceae	*Hilleria latifolia* H. Walter
Phyllanthaceae	*Bridelia micrantha* (Hochst.) Baill.
Phyllanthaceae	*Macaranga assas* Amougou
Phyllanthaceae	*Phyllanthus muellerianus* (Kuntze) Exell
Pittosporaceae	*Pittosporum viridiflorum* Sims subsp. Dalzielii (Hutch.) Cuf.
Proteaceae	*Protea madiensis* Oliv.
Rhizophoraceae	*Cassipourea zenkeri* (Engl.) Alston
Rosaceae	*Prunus africana* (Hook.f.) Kalkman
Rubiaceae	*Canthium cf henriquerianum*
Rubiaceae	*Euclinia longiflora* Salisb.
Rubiaceae	*Gardenia lutea*
Rubiaceae	*Gardenia vogelii* Hook.f.ex Planch
Rubiaceae	*Ixora anemodesma* K. Schum
Rubiaceae	*Ixora bauchiensis* Hutch. & Dalziel
Rubiaceae	*Leptactina* sp.
Rubiaceae	*Polysphaeria arbuscula* K. Schum.
Rubiaceae	*Psychotria* cf *ebensis* K. Schum
Rubiaceae	*Psychotria peduncularis* (Salisb.) Steyerm.
Rubiaceae	*Psychotria* sp.
Rubiaceae	*Psychotria vogeliana* Benth.
Rubiaceae	*Rothmannia ebamutensis* Sonké
Rubiaceae	*Rothmannia malaensis*
Ruscaceae	*Dracaena aubryana* Brongn.ex E. Morren
Ruscaceae	*Dracaena surculosa* Lindl.
Rutaceae	*Clausena anisata* (Wild.) Hook.f.ex Benth.
Sapindaceae	*Paullinia pinnata* L.
Sapotaceae	*Porteria pierrei* (A.Chev.) Baehni
Smilacaceae	*Smilax kraussiana* Meisn.
Thymelaeaceae	*Dicranolepis disticha* Planch.
Violaceae	*Rinorea dentata* (P.Beauv.) O.Kuntze
Zingerberaceae	*Aframomum daniellii* (Hook.f.) K.Schum.
Zingiberaceae	*Renealmia* sp.

Appendix 5.3. Summary of density, number of species, above-ground biomass, carbon, and Basal area in 17 ha plot across five vegetation types in Kimbi-Fungom National Park, Cameroon.

Plot	Vegetation type	Elevation (m)	Stem Density	Tree Density	Number of Species	AGB (t/ha)	Carbon (t/ha)	BA (m2/ha)
1	PSF	481	407	404	65	346.8	173.4	30.2
2	PSF	481	389	389	63	360.3	180.2	30.6
3	PSF	474	381	375	58	361.9	181	32.4
4	GS_MV_PSF	429	353	335	58	199.7	99.9	18.5
5	PF_GS	433	237	213	43	137.2	68.6	14.6
6	GS_GAL_SF	439	313	292	57	149.6	74.8	14.8
7	GS_GAL_SF	439	356	311	50	86.2	43.1	11.9
8	WS_MV_GAL	396	251	190	29	48.3	24.2	6.8
9	WS	407	314	250	32	68.9	34.5	9.6
10	WS_PSF	410	241	183	32	60.8	30.4	7.5
11	SF_GAL_WS	422	202	157	27	89.4	44.7	8.6
12	GS_GAL	898	289	244	36	80.6	40.3	10.6
13	GS_GAL	898	297	292	34	86	43	10.9
14	GS	898	298	249	30	93.9	47	11.7
15	GS_GAL	846	280	250	33	88	44	11.1
16	GS_MV	846	221	194	34	78.8	39.4	10.1
17	GS_PSF	846	296	259	52	200.4	100.2	17.4
	Total		5125	4587	733	2537.2	1268.9	257.4
	Mean		301.5	269.8	43.1	149.2	74.6	15.1
	Standard dev.		60.4	74.1	13.3	104.8	52.4	8.2

GF=Gallery forest, G/WS=Grassland/Woody savanna, MV=Mixed vegetation, PSF=Primary semi-deciduous Forest, SF=Secondary Forest

Vegtype=Vegetation types, Elev. (m) =Elevation, SD=Stem Density, TD=Tree Density, #spp=Number of species/ha, AGB (t/ha) = above ground biomass, CO_2 (t/ha) =Carbon dioxide, BA (m^2/ha) =Basal area.

Appendix 5.4 Species list and abundance in the Kimbi-Fungom National Park, Cameroon

Family	Species	GF	G/WS	MV	PSF	SF	Total
Anacardiaceae	*Lannea microcarpa* Engl. & K. Krauce	-	2	-	8	1	11
Anacardiaceae	*Lannea schimperi* (Hochst.ex. A. Rich.) Engl.	3	50	2	-	-	55
Anacardiaceae	*Lannea* sp.1	-	1	-	1	-	2
Anacardiaceae	Lannea sp.2	10	27	4	13	6	60
Anacardiaceae	*Pseudospondias microcarpa* (A.Rich.) Engl.	1	-	4	85	7	97
Anacardiaceae	*Sorindeia grandifolia* Engl.	-	-	-	95	-	95
Annonaceae	*Annona senegalensis* Pers.	2	56	1	-	-	59
Annonaceae	*Cleistopholis patens* (Benth.) Engl. & Diels.	-	-	-	3	-	3
Annonaceae	*Cleistopholis* sp.	-	-	-	2	-	2
Annonaceae	*Cleistopholis staudtii* Engl. & Diels.	-	-	-	2	1	3
Annonaceae	*Monodora* sp.2	-	-	-	1	1	2
Annonaceae	*Monodora tenuifolia* Benth.	-	-	-	2	-	2
Apocynaceae	*Alstonia boonei* De Wild	-	-	-	1	1	2
Apocynaceae	*Funtumia elastica* (Preuss) Stapf	-	-	-	20	1	21
Apocynaceae	*Holarrhena floribunda* (G.Don) Dur & Schinz	1	6	-	2	-	9
Apocynaceae	*Rauvolfia caffra* Sond.	-	-	-	6	-	6
Apocynaceae	*Rauvolfia* sp.	-	-	-	1	-	1
Apocynaceae	*Rauvolfia vomitoria* Afzel.	-	-	-	6	-	6
Apocynaceae	*Voacanga africana* Stapf	-	-	-	1	-	1
Araliaceae	*Cussonia arborea* Hochst.ex.A.Rich.	3	105	2	-	-	110
Araliaceae	*Polycias fulva* (Hiern) Harms	1	9	-	7	1	18
Arecaceae	*Elaeis guineensis* Jacq.	-	-	1	43	5	49
Bignoniaceae	*Markhamia tomemtosa* (Benth.) K. Schum.	-	-	-	2	-	2
Bignoniaceae	*Newbouldia laevis* (P. Beauv.) Seeman ex Bureau	-	-	-	35	-	35
Bignoniaceae	*Spathodea campanulata* P. Beauv.	-	6	-	-	7	13
Bignoniaceae	*Stereospermum kunthianum* Cham.	-	5	-	-	-	5
Bombacaceae	*Bombax buenopozense* P. Beauv.	1	12	-	11	9	33
Burseraceae	*Canarium schweinfurthii* Engl.	1	1	1	12	-	15
Burseraceae	*Dacryodes* sp.	-	-	-	1	-	1
Cecropiaceae	*Musanga cecropioides* R.Br.ex Tedlie	-	-	-	2	-	2
Cecropiaceae	*Myrianthus arboreus* P. Beauv.	-	-	-	1	-	1
Chrysobalanaceae	*Magnistipula butayei* De Wild.	-	1	-	-	-	1
Chrysobalanaceae	*Magnistipula butayei* subsp. *balingembeaensis* De Wild.	-	-	-	2	-	2
Chrysobalanaceae	*Maranthes glabra* (Oliv.) G.T. Prance	1	5	15	237	2	260
Chrysobalanaceae	*Parinari curatellifolia* Planch.ex Benth.	-	14	-	-	-	14
Chrysobalanaceae	*Parinari* sp.1	-	-	-	1	-	1
Clusiaceae	*Garcinia* cf *mannii* Oliv.	-	-	-	1	-	1

Clusiaceae	*Garcinia epunctata* Stapf	-	-	-	10	4	14
Clusiaceae	*Mammea africana* Sabine	-	-	-	3	-	3
Clusiaceae	*Symphonia globulifera* L.f.	-	-	-	1	-	1
Combretaceae	*Combretum* sp.	2	12	4	3	-	21
Combretaceae	*Terminalia glaucescens* Planch. ex Benth.	6	231	1	2	2	242
Ebenaceae	*Diospyros* sp.	-	-	-	1	-	1
Euphorbiaceae	*Alchornea cordifolia* (Schum. & Thonn.) Müll.Arg.	1	3	-	-	-	4
Euphorbiaceae	*Macaranga spinosa* Müll.Arg.	-	-	-	-	2	2
Euphorbiaceae	*Neoboutonia velutina* Prain	-	6	-	-	-	6
Euphorbiaceae	*Ricinodendron heudelotii* (Baill.) Pierre ex Baill.	4	4	-	17	18	43
Fabaceae	*Afzelia africana* Sm.	1	1	-	5	-	7
Fabaceae	*Afzelia bipindensis* Harms	2	-	-	4	-	6
Fabaceae	*Albizia adianthifolia* (Schum.) W.F. Wright	1	1	-	5	6	13
Fabaceae	*Albizia* sp.	-	2	-	-	-	2
Fabaceae	*Albizia zygia* (DC.) J.F. Macbr.	5	5	-	11	17	38
Fabaceae	*Angylocalyx pynaertii* De Wild.	-	-	-	2	-	2
Fabaceae	*Anthonotha macrophylla* P.Beauv.	-	-	-	13	4	17
Fabaceae	*Baphia buettneri* Harms subsp. *hylophila* (Harms) Soladoye	-	-	-	12	5	17
Fabaceae	*Baphia* sp.	-	-	-	2	-	2
Fabaceae	*Brachystegia eurycoma* Harms	-	-	1	70	6	77
Fabaceae	*Cassia arereh* Delile	1	4	-	-	-	5
Fabaceae	*Daniellia oliveri* (Rolfe) Hutch. & Dalziel	20	147	1	1	1	170
Fabaceae	*Dialium* cf *pachyphyllum* Harms	-	-	3	10	-	13
Fabaceae	*Dialium* sp.	-	-	-	2	-	2
Fabaceae	*Entada abyssinica* Steud. ex A. Rich.	3	116	-	1	-	120
Fabaceae	*Erythrina senegalensis* A.DC.	-	1	-	-	-	1
Fabaceae	*Erythrophleum ivorense* A. Chev.	-	-	-	12	-	12
Fabaceae	*Erythrophleum suaveolens* (Guill. & Perr.) Brenan	3	14	4	28	1	50
Fabaceae	*Parkia africana* R.Br.	1	13	-	1	8	23
Fabaceae	*Parkia filicoidea* Welw. ex Oliv.	-	-	-	3	-	3
Fabaceae	*Penthaclethra macrophylla* Benth.	-	-	-	3	-	3
Fabaceae	*Pericopsis laxiflora* (Benth.) Van Meeuwen	3	39	-	-	-	42
Fabaceae	*Piliostigma thonningii* (Schum.) Milne-Redh.	4	111	4	-	-	119
Fabaceae	*Pterocarpus erinaceus* Poir	1	1	-	-	-	2
Fabaceae	*Pterocarpus osun* Craib	-	-	-	7	-	7
Fabaceae	*Pterocarpus soyauxii* Taub.	-	-	1	14	-	15
Gentianaceae	*Anthocleista djalonensis* A. Chev.	-	1	-	4	10	15
Hymenocardiaceae	*Hymenocardia acida*	11	237	1	-	-	249

Hyperaceae	*Harungana madagascariensis* Poir.	7	29	-	-	7	43
Hypericaceae	*Psorospermum febrifugum* Spach.	2	29	-	-	-	31
Hypericaceae	*Psorospermum* sp.4	-	-	-	1	-	1
Icacinaceae	*Rhaphiostylis* sp.	-	-	-	1	-	1
Irvingiaceae	*Irvingia grandifolia* (Engl.) Engl.	-	-	-	1	-	1
Irvingiaceae	*Irvingia wombulu* Vermoesen	-	-	-	6	1	7
Irvingiaceae	*Klainedoxa gabonensis* Pierre	-	-	-	1	1	2
Irvingiaceae	*Klainedoxa* sp.	-	-	-	1	-	1
Lamiaceae	*Vitex* cf *simplicifolia*	2	-	-	-	-	2
Lamiaceae	*Vitex doniana* Sweet	13	55	9	6	1	84
Lamiaceae	*Vitex grandifolia* Gürke	-	-	-	3	-	3
Lamiaceae	*Vitex rivularis* Gürke	-	-	1	1	-	2
Lauraceae	*Beilschmiedia anacardioides* (Engl. & Krause) Robyns & Wilczeck	-	-	1	2	-	3
Lauraceae	*Beilschmiedia gaboonensis* (meissn.) Benth. & Hook.f.	-	-	-	1	-	1
Lecythidaceae	*Napoleonaea imperialis* P.Beauv.	-	-	1	8	5	14
Loganiaceae	*Strychnos* sp.2	-	-	-	1	-	1
Loganiaceae	*Strychnos* sp.3	-	2	-	-	-	2
Malvaceae	*Cola caricaefolia* K. Schum	1	-	5	68	4	78
Malvaceae	*Cola cordifolia* (Cav.) R.Br.	1	-	-	4	-	5
Malvaceae	*Cola* sp.	-	-	-	1	1	2
Malvaceae	*Cola* sp.2	1	-	-	-	-	1
Malvaceae	*Microcos flavescens* Juss	-	4	-	-	-	4
Malvaceae	*Sterculia tragacantha* Lindl.	4	3	-	13	10	30
Meliaceae	*Entandrophragma angolense* (Welw.) C. DC.	-	-	2	27	-	29
Meliaceae	*Entandrophragma candollei* Harms	-	-	-	30	-	30
Meliaceae	*Trichilia rubescens* Oliv.	-	-	-	-	1	1
Meliaceae	*Trichilia* sp.	-	2	-	-	-	2
Moraceae	*Antiaris toxicaria* Lesch.	-	-	-	3	4	7
Moraceae	*Ficus abutilifolia* (Miq.) Miq.	-	-	-	3	-	3
Moraceae	*Ficus adolfi-friderici* Mildbr.	-	-	-	-	1	1
Moraceae	*Ficus bubu* Warb.	-	-	-	1	1	2
Moraceae	*Ficus* cf *sur* Forssk.	-	3	-	1	-	4
Moraceae	*Ficus exasperata* Vahl	-	4	-	3	1	8
Moraceae	*Ficus glumosa* Delile	3	18	-	1	8	30
Moraceae	*Ficus mucuso* Welw.ex Ficalho	-	-	-	3	-	3
Moraceae	*Ficus natalensis* Hochst.	-	-	1	-	-	1
Moraceae	*Ficus* sp.10	-	-	-	3	-	3
Moraceae	*Ficus* sp.2	-	9	7	-	6	22
Moraceae	*Ficus* sp.3	-	1	-	-	-	1

Moraceae	*Ficus* sp.5	-	1	-	-	-	1
Moraceae	*Ficus* sp.8	-	29	1	-	-	30
Moraceae	*Ficus sur* Forssk.	1	4	-	-	-	5
Moraceae	*Ficus vallis-choudae* Delile	-	15	-	-	-	15
Moraceae	*Ficus vogeliana* (Miq.) Miq.	2	6	-	-	3	11
Moraceae	*Milicia excelsa* (Welw.) C.C. berg	-	1	-	5	-	6
Moraceae	*Trilepisium madagascariense* DC.	-	-	-	6	-	6
Myristicaceae	*Pycnanthus angolensis* (Welw.) Exell	6	1	1	30	2	40
Myrtaceae	*Syzygium guineense* (Wild.) DC	8	60	-	1	-	69
Ochnaceae	*Lophira lanceolata* Tiegh. Ex Keay	8	186	4	-	-	198
Ochnaceae	*Ochna afzelii* R.Br. ex Oliv.	-	11	-	1	-	12
Ochnaceae	*Ochna* sp.	-	-	-	1	-	1
Olacaceae	*Olax subscorpioidea* Oliv.	-	-	-	7	2	9
Pandanaceae	*Pandanus candelabrum* P. Beauv.	-	-	-	-	6	6
Passifloraceae	*Adenia* sp.	-	-	-	1	-	1
Passifloraceae	*Barteria fistulosa* Mast.	-	-	-	2	-	2
Phyllanthaceae	*Antidesma chevalieri*	-	1	-	1	-	2
Phyllanthaceae	*Bridelia atroviridis* Müll. Arg.	-	-	-	1	-	1
Phyllanthaceae	*Bridelia ferruginea* Benth.	-	4	-	-	-	4
Phyllanthaceae	*Bridelia grandis* Pierre ex Hutch.	-	1	-	3	-	4
Phyllanthaceae	*Bridelia scleroneura* Müll.Arg.	1	66	1	-	-	68
Phyllanthaceae	*Bridelia* sp.	1	3	-	-	-	4
Phyllanthaceae	*Macaranga monandra* Müll.Arg.	-	-	-	-	4	4
Phyllanthaceae	*Margaritaria discoidea* (Baill.) Webster	3	20	3	20	6	52
Phyllanthaceae	*Spondianthus preussii* Engl.	-	-	7	93	2	102
Phyllanthaceae	*Uapaca guineensis* var. *guineensis* Müll. Arg.	-	-	-	21	-	21
Phyllanthaceae	*Uapaca paludosa* Aubrév. & Léandri	-	1	-	53	2	56
Phyllanthaceae	*Uapaca togoensis* Pax	96	86	20	11	-	213
Rhamnaceae	*Maesopsis eminii* Engl.	3	1	-	34	-	38
Rhizophoraceae	*Cassipourea zenkeri* (Engl.) Alston.	-	-	-	4	-	4
Rubiaceae	*Aidia genipiflora* (DC.) Dandy	-	-	-	2	-	2
Rubiaceae	*Aidia* sp.	-	-	-	1	-	1
Rubiaceae	*Craterispermum laurinum* (Poir) Benth.	-	-	-	37	-	37
Rubiaceae	*Crossopteryx febrifuga* (Afzel. ex G.Don) Benth.	8	225	1	-	-	234
Rubiaceae	*Cuviera* sp.	-	1	-	-	-	1
Rubiaceae	*Hallea stipulosa* (DC) Leroy	-	-	-	2	36	38
Rubiaceae	*Ixora euosmia* K. Schum.	-	-	-	31	-	31
Rubiaceae	*Ixora* sp.2	-	-	-	-	2	2
Rubiaceae	*Macrosphyra longistyla* (DC.) Hiern	2	-	-	18	-	20
Rubiaceae	*Morelia senegalensis* A. Rich.ex DC.	2	1	-	8	2	13

Rubiaceae	*Nauclea latifolia* SM.	3	225	8	-	-	236
Rubiaceae	*Pavetta baconiella* Bremek.	-	-	-	3	-	3
Rubiaceae	*Pavetta calothyrsa* Bremek.	-	-	-	1	-	1
Rubiaceae	*Rothmannia* sp.1	-	-	-	2	-	2
Salicaceae	*Homalium africanum* (Hook.f.) Benth.	-	-	-	2	-	2
Sapindaceae	*Allophyllus bullatus* Radlk.	2	17	-	3	-	22
Sapotaceae	*Chrysophyllum ubanguiense* (De Wild.) Govaerts	2	-	3	75	-	80
Sapotaceae	*Englerophytum stelechanthum* Krause	-	-	-	1	-	1
Sapotaceae	*Pouteria alnifolia* (Baker) Roberty	-	-	-	1	-	1
Sapotaceae	*Synsepalum stipulatum* (Radlk.) Engl.	-	-	-	4	-	4
Simaroubaceae	*Quassia sanguinea* Cheek & Jongkind	-	-	-	4	-	4
Simaroubaceae	*Quassia sylvestris* Cheek & Jongkind	-	1	-	-	1	2
Ulmaceae	*Celtis philippensis* Blanco	-	-	-	7	-	7
Ulmaceae	*Trema orientalis* (L.) Blume	1	1	-	7	12	21
	Shirakiopsis elliptica (Hochst. Esser	-	-	-	1	-	1
	Grand Total	276	2384	129	1559	259	4607

GF=Gallery forest, G/WS=Grassland/Woody savanna, MV=Mixed vegetation, PSF=Primary Semi-deciduous Forest, SF=Secondary Forest

CHAPTER SIX

TEMPORAL LAND-COVER CHANGES IN TROPICAL FORESTS OF THE CONGO BASIN: CASE STUDIES OF A WET FOREST OF RUMPI HILLS FOREST RESERVE AND A DRY FOREST OF KIMBI FUNGOM NATIONAL PARK IN CAMEROON

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Preface

Chapter six deals with the temporal evaluation of land cover changes in the wet Rumpi Hills Forest Reserve and the dry Kimbi Fungom National Park.

ABSTRACT

The concept of linking deforestation in Tropical forest to anthropogenic activities has been a major driver to biodiversity loss, biomass and forest carbon depletion in the tropics. This problem is becoming alarming in the Congo Basin. Therefore, continuous assessment of spatial and temporal vegetation changes is warranted for understanding the interaction between humans and the forests, as well as the effectiveness of long-term forest management practices. In this chapter, temporal and spatial land-cover changes in two tropical forests: wet forest of Rumpi Hills Forest Reserve and a dry forest of Kimbi Fungom National Park in Cameroon were assessed, compared and discussed. Satellite images from Rumpi Hills (2000 and 2015) and Kimbi Fungom forests (1979 and 2015) were used to compare past and present vegetation (forest cover changes over time). Remote sensing data (Landsat images) were downloaded from the Global Land Cover Facility (GLCF) and United States Geological Survey (USGS) websites and forest cover changes compared over time at both sites in relation to land-use changes that resulted from anthropogenic activities.

Result from Rumpi Hills Forest Reserve over time (2000-2015) shows no representative difference on forest types and other parameters, though there were slight changes in the sizes bringing the entire size (area) from 453 km^2 in 1936 to 446.66 km^2 in 2015. This finding suggests that Rumpi Hills Forest Reserve is generally intact and is encouraging. In contrast, in the dry forest of Kimbi Fungom National Park there was evidence of deforestation all over the park with locations in the west around Gayama and Munkep being the most affected. Interestingly, forest regeneration was observed south of the Park. An increase in deforestation over this time (1936-2015) in the Fungom compartment and in the Kimbi compartment from 1964-2015 coincided with the presence of access roads, and population increase. In the Kimbi Fungom National Park, forest cover changes from 978.38 km^2 in 1979 to 972.72 km^2 in 2015 with a degree of accuracy of 82.41% in 1979 and 71.52% in 2015. The lack of representativechange in the vegetation of Rumpi Hills Forest Reserve can be ascribed to its inaccessibility. This has led to its high diversity, and endemism. The numerous linking roads and villages that occur within and around the Kimbi Fungom National Park are the main causes for the high anthropogenic activities within the park. Thus, effective land-use planning and management practices are needed to enhance the park's conservation and biodiversity status.

Key words: Land use, Forest cover changes, management practices, Landsat images, Rumpi Hills, Kimbi Fungom, Gayama, and deforestation.

6.1 INTRODUCTION

Land-use and land-cover changes have been identified as major threats to biodiversity, biomass, and forest carbon on a national, regional, and global scale, with forest ecosystems being the most affected

(Lugo, 1988; Meyer et al., 1996; Foley et al., 2005, Aukema et al., 2017). The vegetation of the wet forest is generally of closed forest that ranges from herbaceous to canopy trees of up to 50 m tall, while the vegetation of dry forest range from semi-deciduous forest with sparse undergrowth, savanna and woody savanna forest with open undergrowth mostly with tall grasses; trees which hardly exceed 20 m tall. Although generally, both dry and wet tropical forests are disappearing rapidly (Turner et al., 1994; WRI and IUCN 1998; Bikié et al., 2000; FAO, 2007; De Wasseige et al., 2009; Haggar et al., 2013), comparatively, dry tropical forests have received heavier impact through forest fire, and overgrazing than wet tropical forests (Risser, 1988). Many reasons have been attributed to these diverse impacts in the tropical wet and dry forest. Dry forests are exposed to higher human activities and tend not to benefit from the same protection status as wet forests. Hence, the wet and dry forest of the Rumpi Hills Forest Reserve (RHFR) and the Kimbi Fungom National Park (KFNP), respectively, were selected for this study. Temporal and spatial land-cover changes in the two tropical forests were assessed, compared and discussed. Analysis of land-cover, land-use, and land management practices using long-term remote sensing analysis to identify high risk zones were used. This method is appropriate because images are obtained from the optical multispectral satellite. This instrument has more than one sensor and the impact to biodiversity is that the sensor takes images of the biodiversity of a place at the time of image capture and changes can not be made in a later time. For instance clould covers on images can not be removed after image capture. The study sought to answer the following research question: To what extent has land-cover changes occurred in the RHFR and the KFNP over time?

6.2 MATERIALS AND METHODS

6.2.1 Study Area

The wet forest of the Rumpi Hills Forest Reserve (RHFR) is located at 4.6-5.0°N and 8.8–9.4°E in a tropical lowland to montane forest at 446.66 km^2 with an elevation range of 50-1778 m above sea level (a.s.l). East of the reserve, is an uplifted cone that forms a plateau at 1778 m a.s.l called Mt Rata. South of this plateau, is a gentle trail, which ascends to the summit. Halfway to the summit is a carbonate-rich vertical cliff and a mosaic of savanna at about 1300-1500 m. West of the summit is covered with huge vertical cliffs, inaccessible that descend into a piedmont forest at mid-elevation (800-1000 m). This forest continues to the west to a lowland rain forest of 50 m a.s.l. The mean annual temperature is 22 °C, but decreases at the summit of Mt Rata. The mean annual rainfall ranges from 4933-5000 mm (Thomas, 1996; Nembot and Tchanou 1998), occurring between April to November. Weather records from

Mundemba, which is < 50 km west of RHFR (1991-2001) gave a mean temperature range of 22.3-30.2°C yr^{-1}, mean radiation of 9.3 yr^{-1}, and mean rainfall of 5139.7 mm yr^{-1}.

The topography and relief of the reserve, and the strong southwest monsoon wind that blows into the reserve from the Ndian creeks have great influence on the different vegetation types and species diversity. This reserve was classified into eight vegetation types (Letouzey, 1985), and is characterized by plant species such as *Oubanguia alata* (Lecythidaceae), *Crateranthus talbotii* (Lecythidaceae), *Strombosia grandifolia* (Olacaceae), *Leonadoxa africana* (Fabaceae), *Tabernaemontana ventricosa* (Apocynaceae), *Dasylepis thomasii* (Achariaceae), *Strombosia* sp. (Olacaceae), *Carapa oreophila* (Meliaceae), *Xylopia africana* (Annonaceae), *Macaranga* sp. (Euphorbiaceae), *Trema orientalis* (Ulmaceae), *Bridelia grandis* (Phyllanthaceae) and *Pauridiantha viridiflora* (Rubiaceae).

The dry semi-deciduous and savanna forest of the Kimbi Fungom National Park (KFNP) is located at 6.5-6.9° N, and 9.8-10.5° E at 953.8 km^2 with an elevation of 350-1100 m a.s.l. The size of Kimbi Fungom National Park is 978.38 km^2. Weather record from Ako, which is < 100 km east of KFNP has a mean annual temperature of 22-27°C with mean annual rainfall record for 2011-2015 at 1881.8 mm yr^{-1}. The dry season here is severe and runs from November to February, with < 100 mm of rainfall during these months. December to February is the driest period, with a peak in January and eight months of rainfall (March to October) each year with a peak in July to September. Despite the eight months of rainfall, monthly readings hardly exceed 350 mm $month^{-1}$ with January recording no rainfall. The vegetation of the dry semi-deciduous and savanna forest of the KFNP is characterized by *Brachystegia eurycoma* (Fabaceae), *Maranthes glabra* (Chrysobalanaceae), *Daniellia oliveri* (Fabaceae), *Hymenocardia acida*, *Terminalia glaucescens* (Combretaceae), *Crossopteryx febrifuga* (Rubiaceae), *Nauclea latifolia* (Rubiaceae), and *Lophira lanceolata* (Ochnaceae).

6.2.2 Image analysis

To understand forest cover changes in the two protected areas over time, optical multispectral satellite images for Rumpi Hills Forest Reserve (RHFR) and Kimbi Fungom National Park (KFNP) were downloaded from the Global Land Cover Facility (GLCF) and United States Geological Survey (USGS) websites (www. Glcf.umiacs.und.edu) and analyzed using the ENVI 4.4 software for land cover changes. The images used comprised of the 60 m Landsat MSS of 1979 (acquired on 14 of March 1979) and a 30 m Landsat 8 image of 2015 (acquired on 6 March 2015) for KFNP to assess land cover changes for a period of 36 years. Landsat ETM+ (30 m) of 2000 (acquired on 10 December 2000) and a 30 m Landsat 8 image of 2015 (acquired on 10 January 2015) for RHFR were also used to assess land cover changes for a period of 15 years. These images were all process and all limitations such as shadows removed before uploading to the website (Teillet et al., 2001). In both studies, only the limits of the study area were taken into consideration. Thus, our results represent all land cover in the core study area excluding the surroundings. The 2015 image used in the analysis for KFNP did not have data for the southern part that represent Kimbi and Donga Mantung extension which is represented here as rivers when compared with the 2000 image. This therefore led to a misrepresentation of water bodies during the analysis as this section was automatically classified as a water body due to the similarity of its reflectance with that of water bodies. The Normalized Differential Vegetation Index (NDVI) that ranges from -1 to 1 was used for vegetation classification. It's usually calculated using bands of 3 and 4 of the optical multispectral satellite images. The NDVI tells us that any index with a negative value indicates no vegetation while 0.1-1 indicates vegetation cover. The usual range for green vegetation is 0.2-0.8, hence, the higher the index, the thicker the vegetation canopy (Cui et al., 2013). The classification method used was supervised classification using the Minimum Distance Classification type. The land-cover analysis carried out allowed verification of pixel values that differ on the different maps over time, 36 years for KFNP and 15 years for RHFR. In the classification scheme, six classes were identified: Springs/streams/rivers, evergreen forest, Atlantic biafran forest, piedmont forest, submontane forest and cloud cover for RHFR. For KFNP, five classes that comprised of bare soil/burnt area, springs/streams/rivers; savanna type 1, savanna type 2, and evergreen forest were identified. In this study, we define bare soil/burnt area as land that has been cleared for agricultural practices and settlements; savanna type 1 represent grassland savanna and fallow farmland;, savanna type 2 represent woody savanna and fallow farmland, and evergreen forest represent dry semi-deciduous forest. Land-use and land-cover changes in the Kimbi Fungom area are prominent and could be ascribed to human activities and natural factors. Post classification comprised of an accuracy assessment to calculate the amount of error that exists in the information that is being produced for KFNP and RHFR. This was realized using the confusion matrix tool in ENVI 4.4. Areas of the various classes were calculated and summarized in the results.

6.3 RESULTS

6.3.1 Land cover classification

To understand the level of precision in this study, an accuracy assessment test was carried out for images at both sites to classify land-use and forest cover changes. This was classified as percentage of producer accuracy which is the accuracy of the original image and the user accuracy which is the accuracy of the outcome image. To get the overall accuracy, the sum of pixels classified correctly was divided by the total number of pixels. The Kappa coefficient (k) is also an accuracy parameter. The accuracy assessment for the Kimbi Fungom forest gave an overall accuracy of 82.4 % for 1979 image and 71.5 % for 2015 image with a Kappa coefficient of 0.74 and 0.65 respectively (Table 6.1). Although, this is below the threshold of 85% (USGS guideline), the records presented here is still appreciated, and a Kappa value of above 0.8 is strongly agreed.

The NDVI for KFNP 1979 ranges from 0.01-0.1 indicating very spare or shrubby vegetation as the value for green vegetation starts from 0.2-0.8. The 2015 NDVI for KFNP reveals more negative NDVI values that relate the high rate of deforestation mostly in the west of figure 6.4. The index ranges from 0.003-0.005 indicating more spare or shrubby vegetation than in the year 1979.

In Rumpi Hills Forest Reserve, the NDVI for 2000 ranges from 0.02-0.3, and due to cloud cover and haze found on the 2015 image, most of the NDVI values were negative. However, the vegetation was underneath the clouds thereby preventing actual vegetation values.

6.3.2 Past and present vegetation: Forest cover changes in the wet Rumpi Hills Forest Reserve

In 2015 the RHFR was realized to contain more than 98.6% of its forest cover (446.7 km^2) of the total land area of 453 km^{-1} in 1937. This was synthesized into six forest cover classes using the minimum distance classification: rivers/streams/springs, clouds, Atlantic Biafran forest, evergreen forest, piedmont forest, and submontane forest. Forest cover classes/forest cover changes are presented in Table 6.2 (class changes over time) and Figure 1 (a & b; the supervised classified images). No representative changes were observed for the different classes analyzed in this reserve between 2000 and 2015 (Table 6.2). This can be attributed to the inaccessibility of this reserve since its creation in 1937 which has limited anthropogenic activities. Graphical representations using pie charts (Figure 6.2) and bar graphs (Figure 6.3) were also made to show the surface area occupied by the different forest cover classes and the changes that have taken place over time from 2000 to 2015. The Atlantic biafran forest dominated the forest cover with 107.06 km^2 total surface area for 2000 and 2015. The total area occupied by springs/streams/rivers (70.65 km^2) is slightly lower than the size of submontane forest (79 km^2). This actually indicates the quantity of water that RHFR is holding for such a long period since its creation in 1937. The impact of cloud covers on images (figure 6.1 A and B) obtained in tropical areas are common (Bastero and Lagmay 2006). This is due to the fact that we are in the tropics and secondly, images were obtained from the optical multispectral satellite that uses more than one sensor (Bastero and Lagmay 2006).

6.3.3 Past and present vegetation: Forest cover changes in the dry semi-deciduous and savanna Kimbi Fungom forest

Broadly, the forest cover of the Kimbi Fungom National Park changed from 978.38 km^2 in 1979 to 972.72 km^2 in 2015 (Table 6.3) giving a reduction of 5.7 km^2 . The class with the greatest observed and calculated change was bare soil/burnt area with an initial value of 19.6 km^2 in 1979 and a value of 151.3 km^2 in 2015. This gave an increase of 131.7 km^2. The western part of the park around Gayama and Munkep was greatly deforested (degraded) with slight changes in the center and southeast of the park. This is strongly attributed to increase population, commercial agriculture, cattle grazing, timber logging, and unsustainable land use management practices. Savanna type 1 changes from 373.8 km^2 in 1979 to 46.4 km^2 in 2015 with a reduction of 327.4 km^2. Savanna type 2 changes from 132.8 km^2 in 1979 to 44.5 km^2 in 2015 with a reduction of 88.3 km^2. This indicates a high rate of deforestation in these forest cover classes. This can be attributed to the fact that these areas are favorable for grazing, settlement, agricultural practices and gathering of fuel wood (Table 6.3 and Figure 6.4A and B). Another factor for this reduction could be the fact that in the 2015 image the Kimbi and Donga Mantung extension here represented as rivers were mostly savanna. The evergreen forest changes from 318.4 km^2 in 1979 to 415.01 km^2 in 2015 with an increment of 96.6 km^2. This implies a high rate of reforestation or it could be as a consequence of the resolution of the images used. The 1979 image had a resolution of 60 m which makes it less accurate than the 30 m 2015 image. The change in springs/streams/rivers from 133.9 km^2 in 1979 to 321.4 km^2 in 2015 with an increment of 187.5 km^2 is not realistic as the area classified as water bodies in 2015 Kimbi and Donga Matung extension had no data (Figures 6.4B, 6.5 and 6.6).

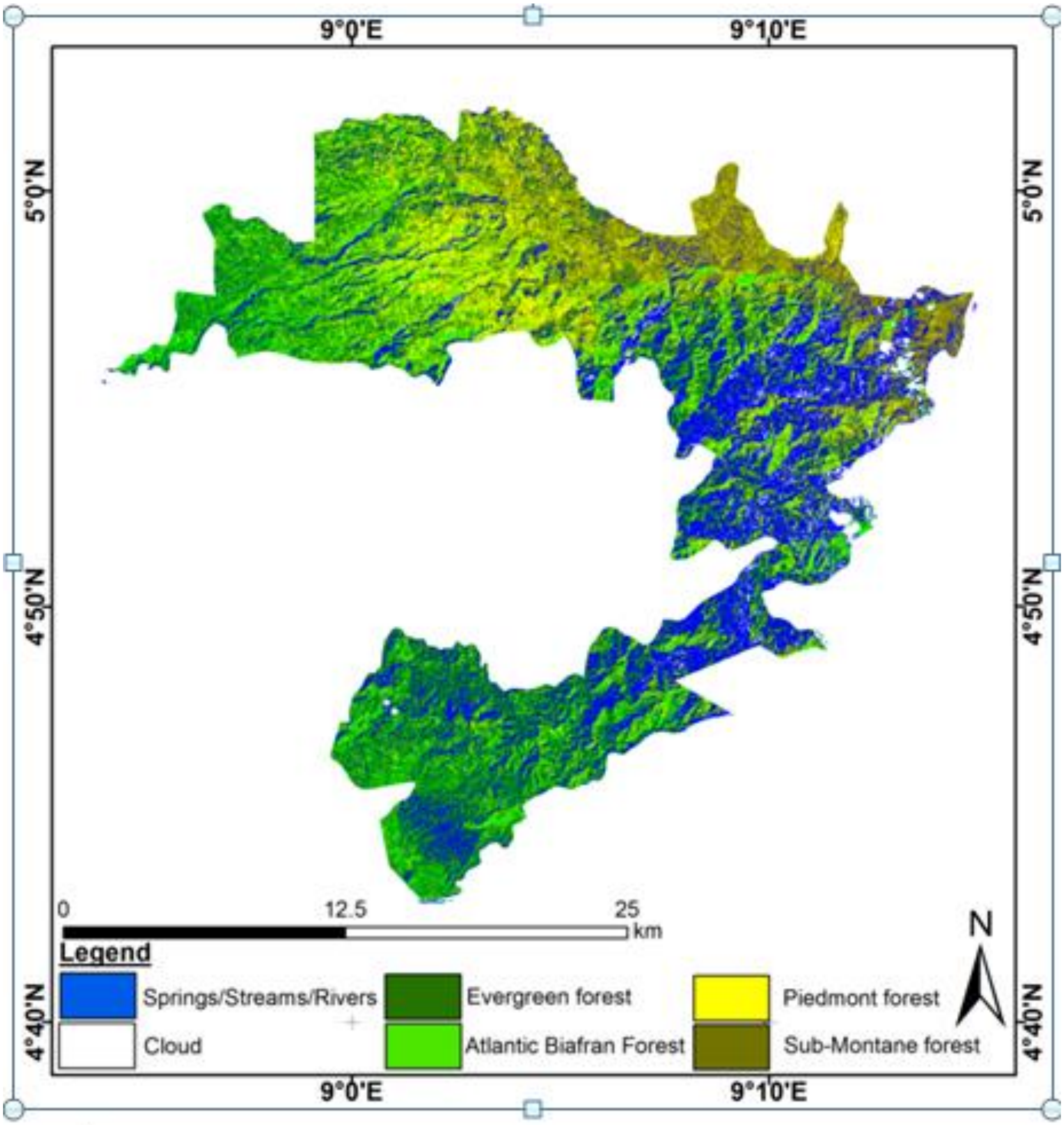
6.4 DISCUSSION

Forest cover changes over a time period of 8 to 10 years and at accurate scale using imageries presented at different time periods remains the most suitable tool for detecting changes in vegetation cover (Mahmood et al., 2010). To date, limited or no study on this subject has been undertaken in the Rumpi Hills and Kimbi Fungom forest. The results obtained in the current study revealed that the Rumpi Hills did not show any representative change in vegetation cover (Figures 6.1 to 6.3). The low net deforestation rate in Rumpi Hills over 79 years (1937-2015) corroborates the study of Rogers (2011), which showed a low deforestation rate of 0.05% in Central Africa. This study further insinuates that the lack of permanent access roads due to the difficult terrain has led to high biodiversity, and low development in protected areas in rural zones (Rogers, 2011). Due to the lack of motorable access roads, villages such as Muyange, Kita and Nalende in the south, Lipenja Mukete, Mbange and Meka in the west, Matamani and Iyombo in the north and Madie 2, Bwembe, and Dikome-Balue in the east depend on subsistence agriculture, which has only little effect on the reserve.

Human population growth over time has been a major problem for tropical forest even in areas that are set aside as protected (Rogers, 2011). The 79 years from the creation of Rumpi Hills Forest Reserve (1937-2015) assessment period used in this study sufficiently accommodates for a reliable determination of the impact of population growth on vegetation cover in a particular landscape. However, it's possible that reduction in population in settlements such as Motindi, Toko, Boa Yenge, Bweme and Bossunga due to migration to larger towns like Meka, Mundemba, Ekondo-Titi, and Kumba might have reduced the pressure on the forest. Thus, the forest cover change for the wet Rumpi Hills Forest Reserve for fifteen years (2000-2015) reveals no significant difference (Figures 6.1 to 6.2). These images bring us to the conclusion that Rumpi Hills is a principle watershed with springs/streams/rivers occupying a surface area of 70.7 km^2 and supplying five basins: Chad, Benue, Sanaga, Congo and Manyu rivers (Ngwa, 1978). This water body flows from the east down to the south supplying rivers Meme and Mungo that empties into the Douala estuary, and to the north and west, rivers Moko, Moriba, and Mana that empties into the Ndian creeks. To the east, it flows down to river Madie that form rivers Mbo and Munaya and continues to Nigeria. The enclave nature of this reserve may have saved it from anthropogenic activities that could potentially lead to climate change and loss of biodiversity.

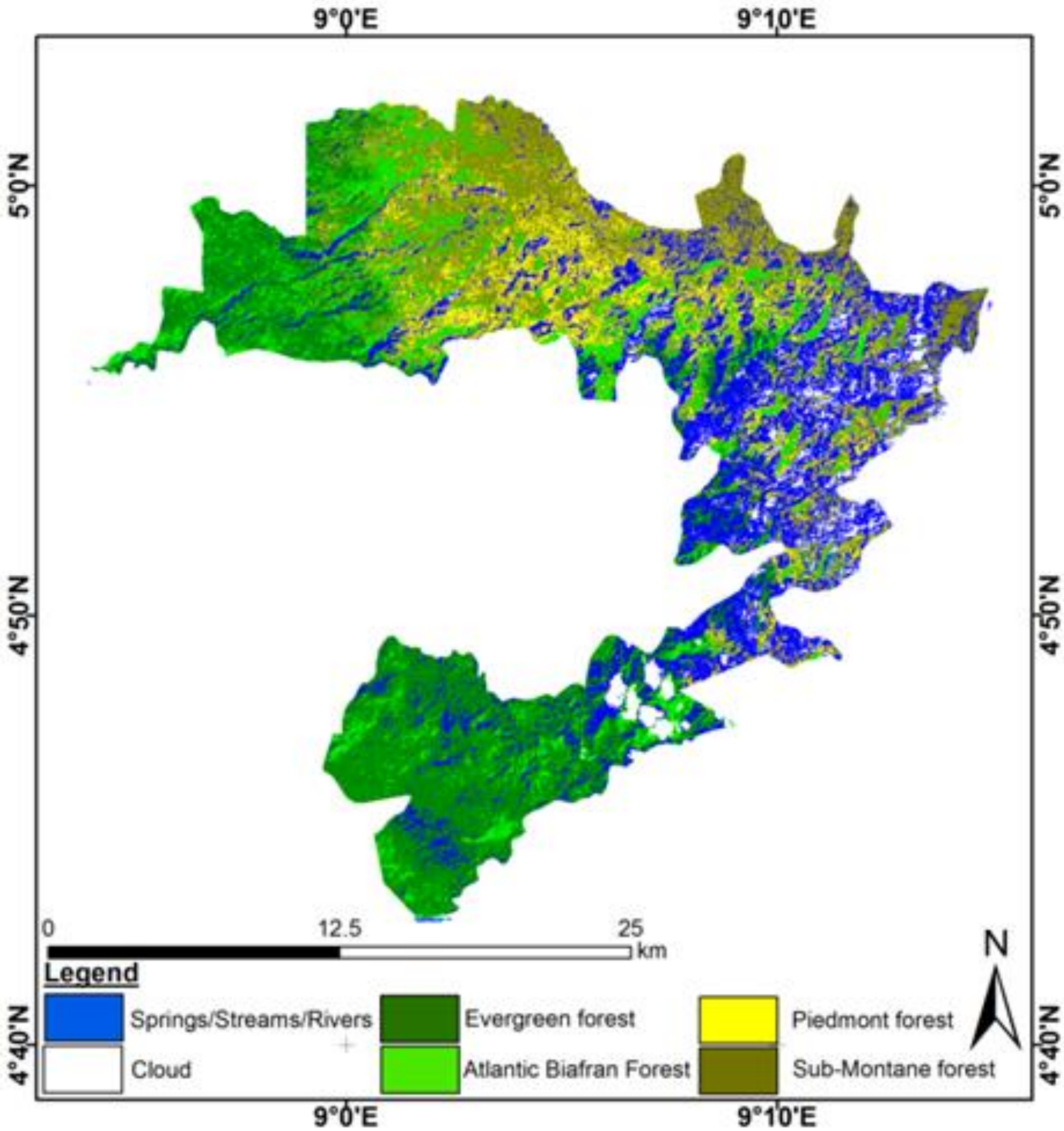
In the Fungom Native Administration Forest Reserve (1936-2015), and the Kimbi Wildlife Sanctuary (1964-2015) that made-up the Kimbi Fungom National Park in 2015 (Forestry Ordinance, 42 of 1936; Rogers, 2011; Sainge, 2016), deforestation was rather massive, albeit evidence of forest regeneration south of the Fungom compartment. This park is made-up of different vegetation types such as the dry semi-deciduous forest with huge trees that ranges in height from 2-45 m tall, and 10-178.2 cm in diameter at breast height, gallery forest, secondary forest, and forest savanna where the understory is mostly composed by tall grasses in the wet season and bare soil with short grasses in the dry season after burning. This vegetation type is exposed to direct sunlight and big trees hardly exceed 15 m in height. Land-use and land-cover changes in the Kimbi Fungom area are pronounced and could be attributed to human activities and natural factors. A change in vegetation from savanna type 1 and 2 (Figure 6.4) to bare soil/burnt area is a clear indication of human activities that resulted from agriculture, deforestation (timber extraction), cattle grazing, over flooding of the numerous streams and rivers. There was increase in bare soil in the west, which can be attributed to population growth and the need for livelihood improvement. However, the analysis indicated that forest regeneration occurs in some areas of Kimbi Fungom National Park. An increment of 96.6 km^2 was recorded in the forest which indicates reforestation (Dami et al., 2014). This is partly due to the abandonment of this reserve since its creation in 1936 as the Fungom forest reserve.

Generally, the land-cover map for the Kimbi Fungom National Park for thirty-seven years (1979-2015) represence differences in land-use patterns (settlements, agriculture, cattle grazing, fuel wood and charcoal gathering, timber extraction, fishing, gathering of non-timber forest products, medicinal plants, etc.). Although there was reforestation in the south, the rate of deforestation in the entire park was more than reforestation rate (Table 6.3, Figure 6.4). The increase of human population, anthropogenic activities cause by agriculture, deforestation (timber exploitation), fuel wood and charcoal was pronounced, especially in the west around Gayama and Munkep villages in 2015 than 1979. These activities will lead to loss of plant and animal species, disrupted forest structure, and diversity; and in a long run may affect the climate of KFNP.



9°0'E
9°10'E
5°0'N
4°50'N
4°40'N
0
12.5
25
km
Legend
Springs/Streams/Rivers
Evergreen forest
Piedmont forest
Cloud
Atlantic Biafran Forest
Sub-Montane forest
N

A



B

Figure 6.1A. 30 m Landsat ETM+ (Enhanced Thematic Mapper) of 2000, B. 30 m Landsat 8 of 2015 for Rumpi Hills Forest Reserve, Cameroon.

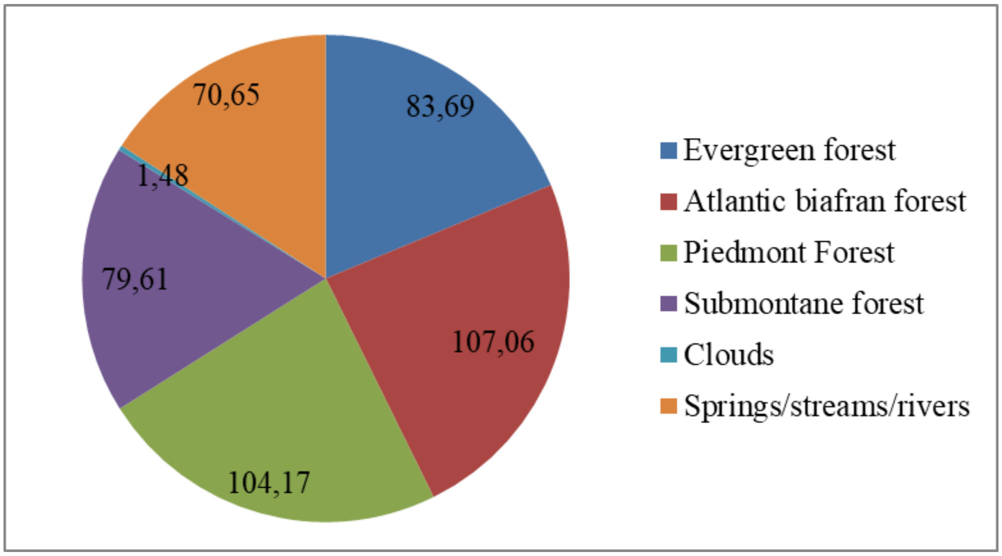


Figure 6.2. Surface area and spatial extentof forest cover types in the Rumpi Hills Forest Reserve, Cameroon from 2000 and 2015

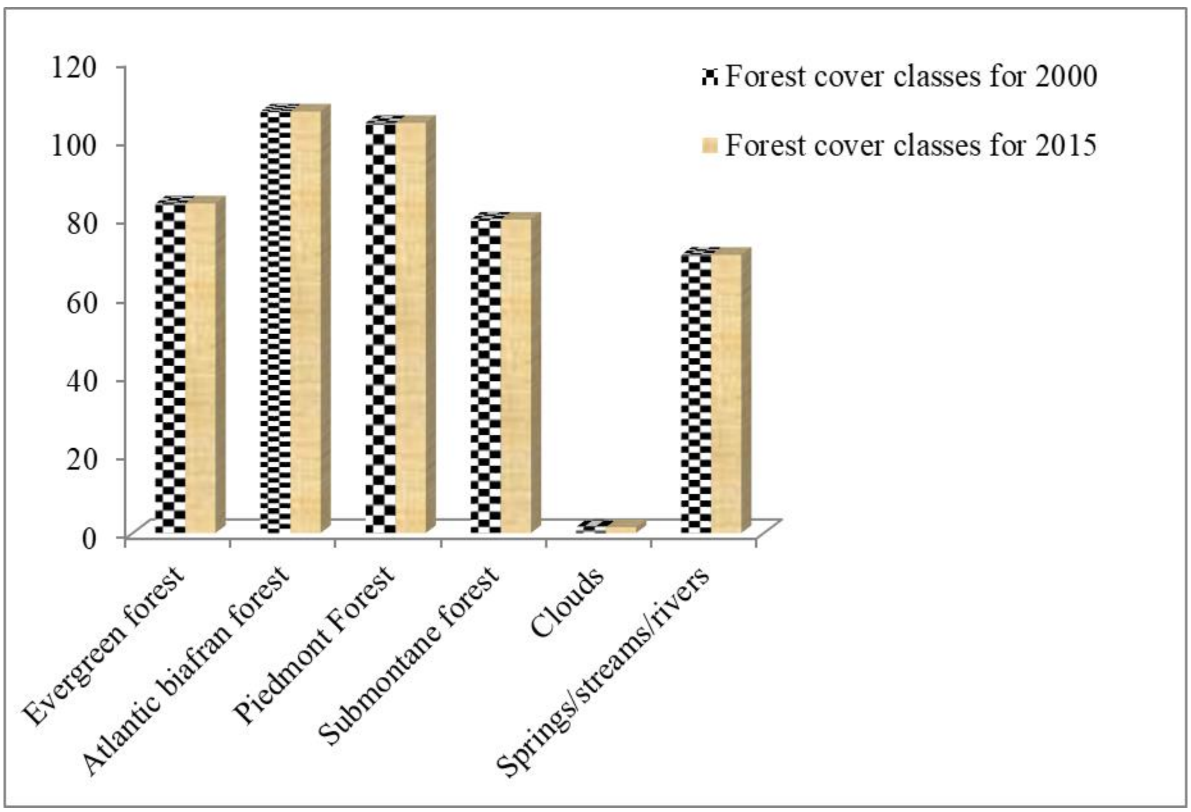
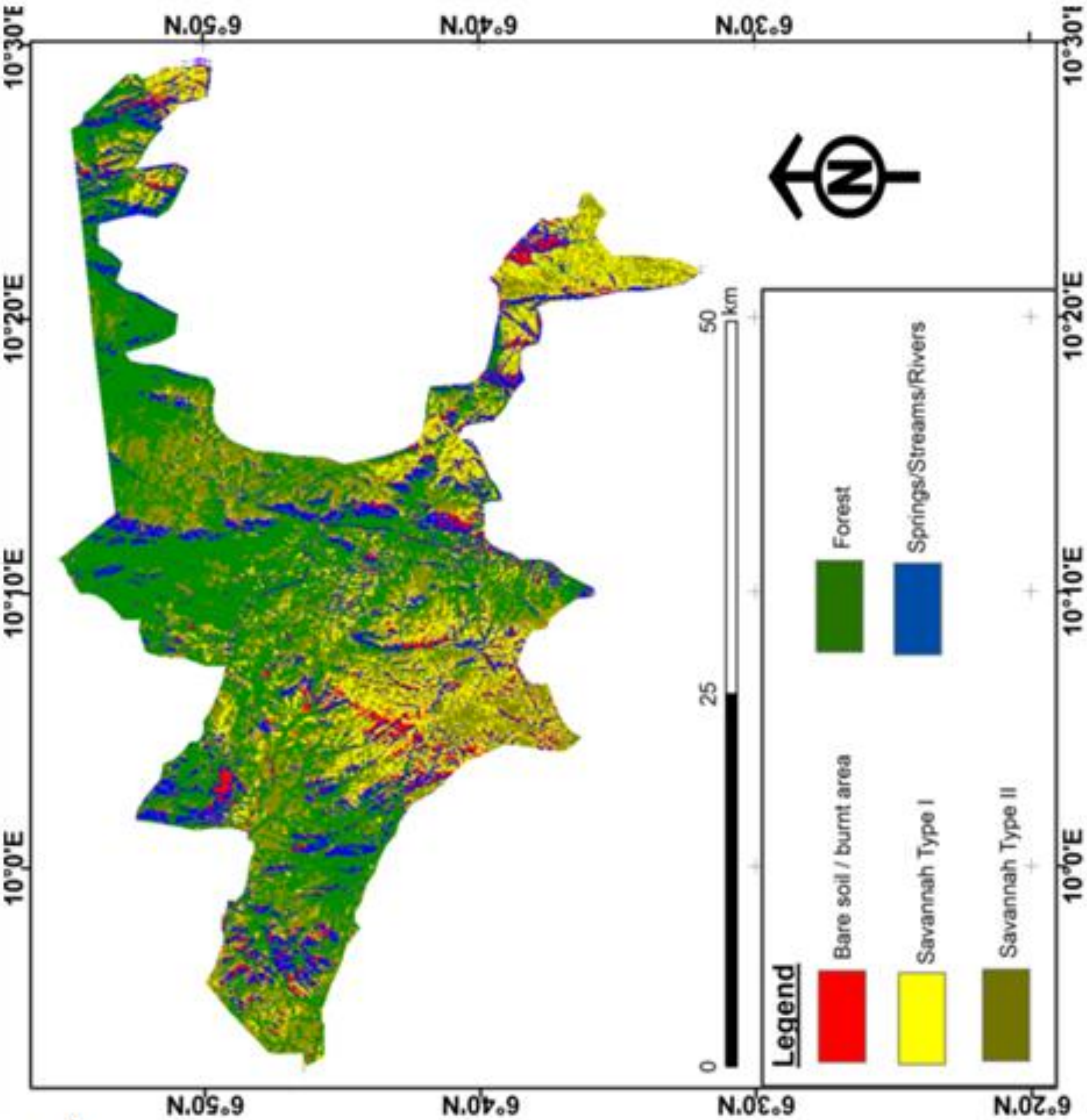
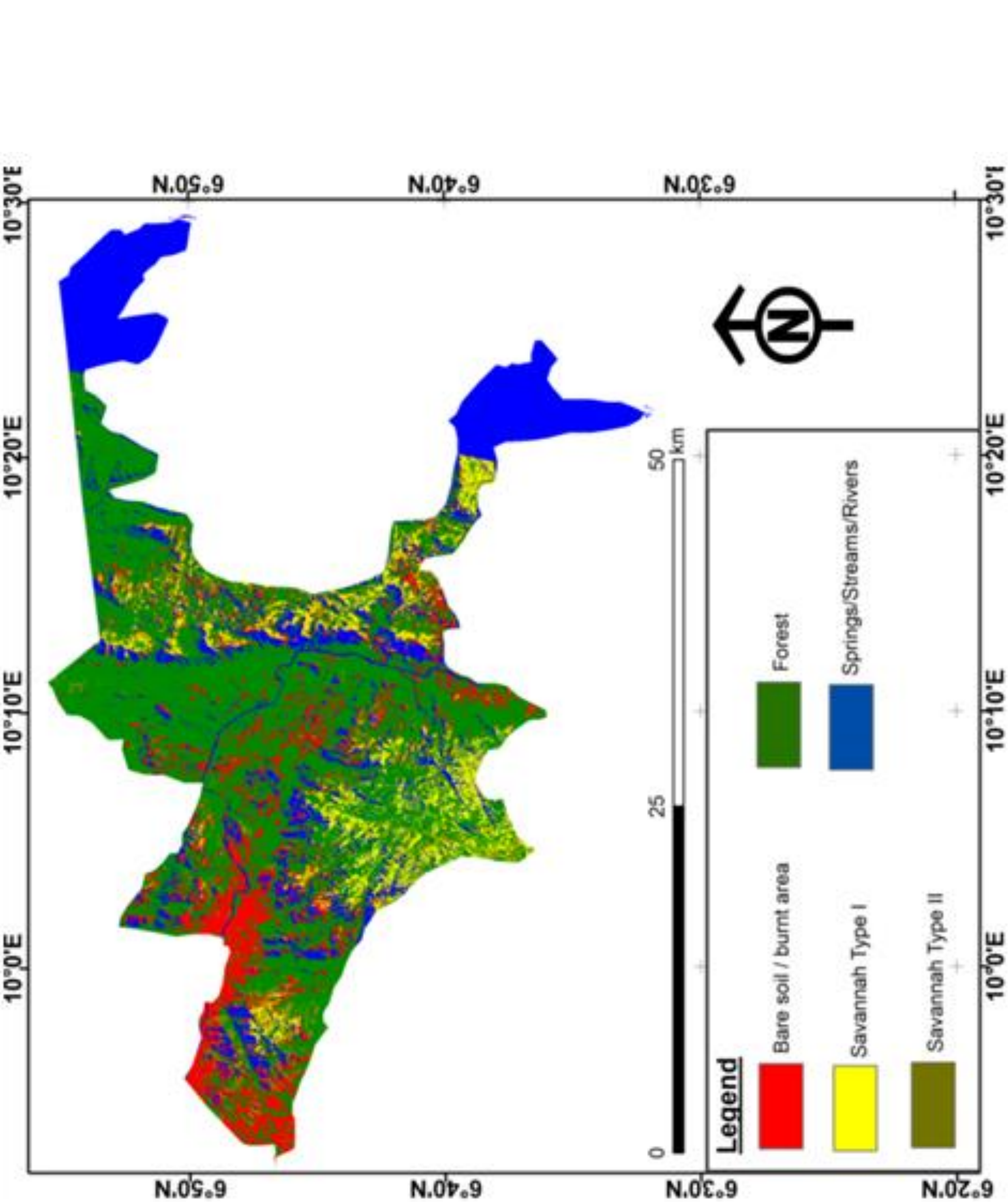


Figure 6.3. Forest cover classes from data collected in 2000 and in 2015 in the Rumpi Hills Forest Reserve, Cameroon.

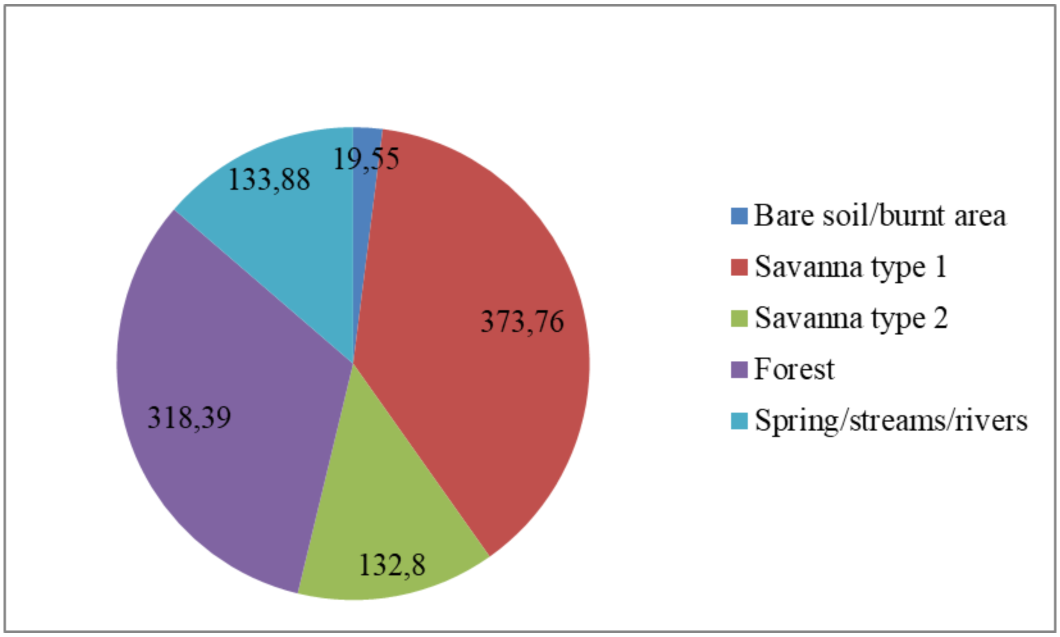

Legend
Bare soil / burnt area
Savannah Type I
Savannah Type II
Forest
Springs/Streams/Rivers
0
25
50
km
10°0'E
10°10'E
10°20'E
10°30'E
6°20'N
6°30'N
6°40'N
6°50'N

A



B

Figure 6.4A. 60 m Landsat MSS (Multispectral Scanner) of 1979, B. 30 m Landsat 8 of 2015 for Kimbi Fungom National Park, Cameroon



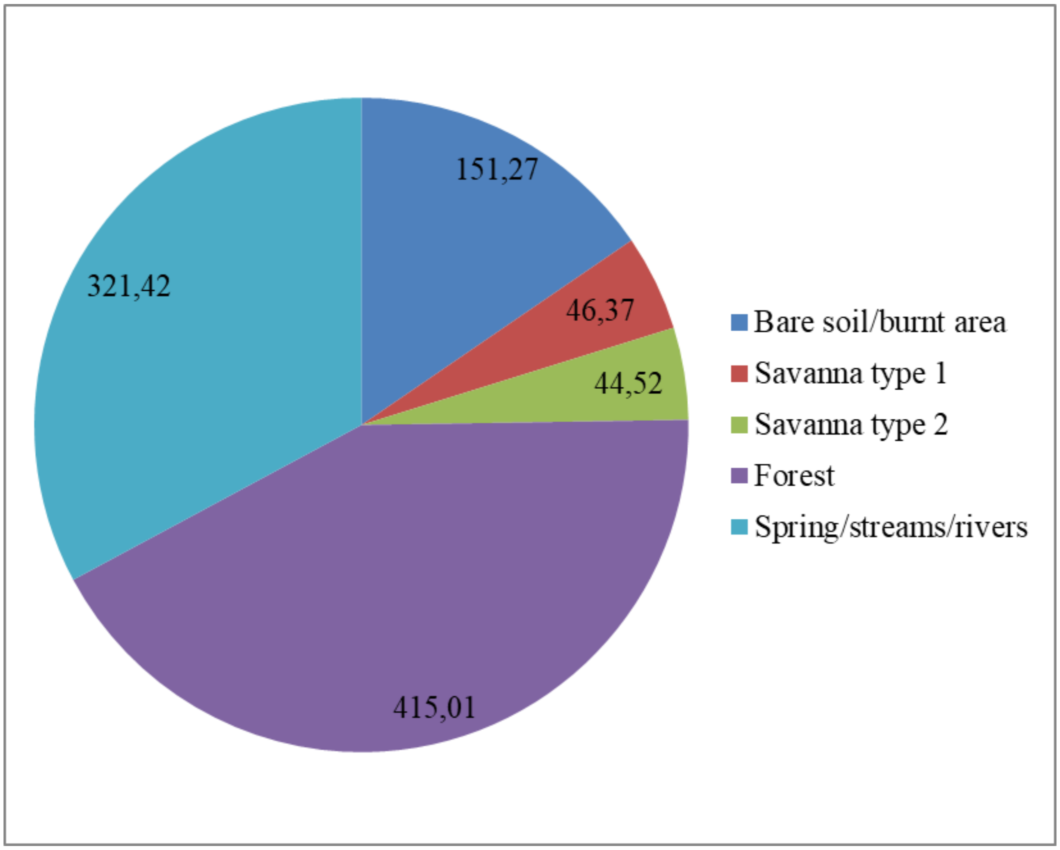


Figure 6.5. Surface area and spatial extentof different cover typesd in the Kimbi Fungom National Park, Cameroon between 1979 (top) and 2015 (bottom)

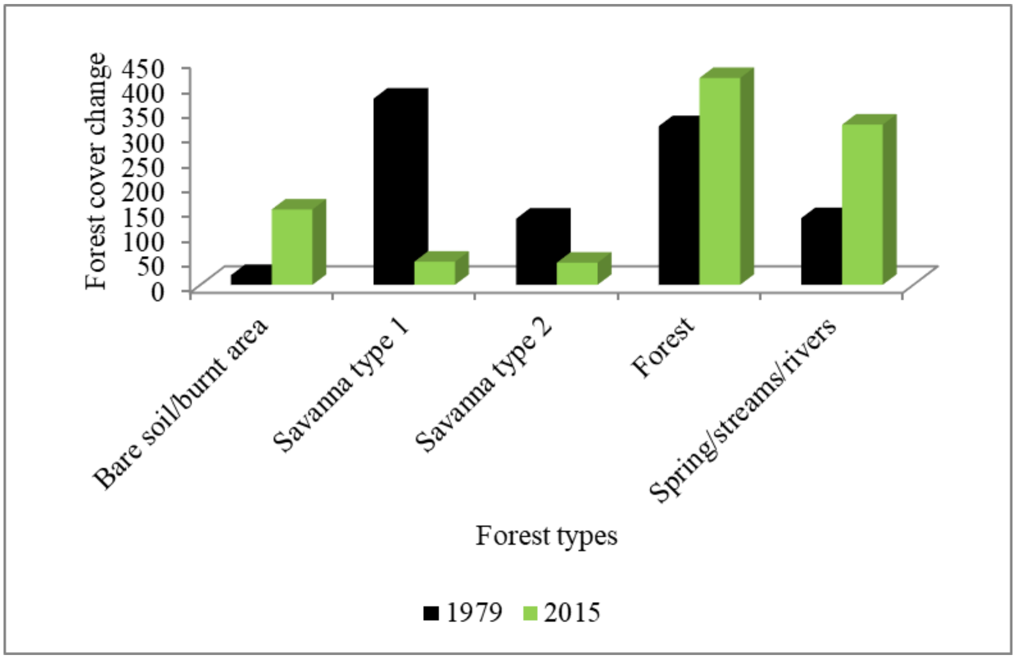


Figure 6.6. Forest covers change for thirty-seven years (1979-2015) in the Kimbi Fungom National Park, Cameroon.

Table 6.1. Accuracy Assessment for Kimbi Fungom National Park, Cameroon

Land cover classes	**1979**		**2015**	
	Producer Accuracy (%)	**User Accuracy (%)**	**Producer Accuracy (%)**	**User Accuracy (%)**
Forest	97.79	99.13	79.76	99.55
Springs / Streams / Rivers	22.92	19.64	100.00	13.73
Bare soil / burnt area	76.12	77.27	90.82	83.96
Savanna Type I	93.80	39.93	4.58	3.11
Savanna Type II	63.70	91.88	10.00	14.86
Over all Accuracy	**82.41 %**		**71.52%**	
Kappa Co-efficient	**0.74**		**0.65**	

Table 6.2. Forest covers change (2000 to 2015) in Rumpi Hills Forest Reserve, Cameroon

Land Cover Classes km^2	Evergreen forest	Atlantic Biafran forest	Piedmont forest	Submontane forest	Rivers	Cloud cover
Initial state image 2000	83.69	107.06	104.17	79.61	70.65	1.48
Final state image 2015	83.69	107.06	104.17	79.61	70.65	1.48
Image difference	00.00	00.00	00.00	00.00	00.00	00.00

Table 6.3. Forest cover Changes (1979 to 2015) Kimbi Fungom National Park, Cameroon

Land Cover Classes km^2	Savanna Type 1	Savanna Type 2	Forest	Bare soil / burnt area	Rivers
Initial state image 1979	373.76	132.8	318.39	19.55	133.88
Final state image 2015	46.37	44.52	415.01	151.27	321.42
Image difference	-327.39	-88.29	96.63	131.72	187.54

CHAPTER SEVEN

7.1 GENERAL DISCUSSION

The continental part of the Cameroon Mountains is among the most species-rich and biodiverse region in Africa (Cheek et al., 2000; Myers et al., 2000; Cheek et al., 2004; Barthlott et al., 2005). This region is the only part of Central Africa with an elevational range from sea level to over 4000 m, and holds a high diversity of plants >6000 species out of the almost 9000 species in Cameroon (Cable and Cheek, 1998; Cheek et al., 2000; Cheek et al., 2004; Onana and Cheek, 2011; Onana, 2011). At the continental level, the continental Cameroon Mountains have species that are represented in mountains of west Africa (e.g., Bersama abyssinica; Cheek et al., 2004) and East Africa (e.g., Polyscias fulva, Strombosia scheffleri, Schlefflera abyssinica, Alangium chinense, Maesa lanceolata; Dowsett-Lemaire, 1989; Thomas and Thomas 1996; Cheek et al., 2000; Cheek et al., 2004; Sainge, 2016).

This region holds >200 species of plants that are considered as threatened (Cheek et al., 2004), which is the highest in Cameroon and perhaps the highest in west and Central Africa (Cheek et al., 2004; Onana and Cheek, 2011), with >80 species endemic (Cheek et al., 2004; Franke, 2004; Sainge et al., 2005; Sainge et al., 2010; Sainge, 2012; Sainge, 2016). Examples of threatened and endemic plant species occurring in the region are Afrothismia saingei, A. fungiformis, Rhaptopetalium geophylax, Schefflera manni, Syzyzium staudtii, Ixora foliosa, Gambeya korupensis, Deinbollia angustifolia, and Begonia pseudoviola. The region hosts three of the seven genera endemic to Cameroon (Hamilcoa, Medusandra, Platytinospora). Finally, the only endemic family in Cameroon (Medusandraceae) is represented here, with its two species: Medusandra mpomiana and M. richardsiana (Cheek et al., 2004; Onana, 2013).

This landscape has been visited and sampled by botanists; nevertheless, their works were mostly centered on surveys of species occurrences, and most of the data are still in non-digitized formats. Data generated from expeditions by these earlier researchers, remains inaccessible to scientists with interest in Africa's biodiversity, particularly those based in Africa. Consequently, attempts to quantitatively analyzed (after Sousa-Baena et al., 2014; Idohou et al., 2015; Kouao et al. 2015) botanical inventory data are stymied by the small numbers of primary occurrence data that are available for the region, and by the large proportion of such data that remain in non-digital formats in institutions in Europe, and America. This study identified botanical inventory gaps, collect detailed biodiversity data and explored the ecological relationships among species diversity, forest structure, carbon storage and altitudinal gradient. Furthermore, the study builds on the pioneering works of other authors (Newberry and Gartlan 1996; Thomas et al., 2003; Kenfack et al., 2006; Gonmadje et al., 2011; Djuikouo et al., 2014) who have worked, documented and found different tree densities across the different landscapes in Cameroon.

The present study revealed that the RHFR is rich in species endemism. In total, seventeen species are endemic to Cameroon with species such as *Deinbollia angustifolia*, and *Gambeya korupensis* endemic in the Korup and Rumpi area, while 43 species were endemic to the lower Guinea forest. This high levels of species diversity and endemism is corroborated by studies of Mittermeiers et al. (1999), Myers et al., (2000), Bergl et al. (2007) and Marchese (2015) who classified the lowland and highland forest of west and central Africa as biodiversity hotspot and concentration sites of endemic species.

The present study also covers different forest types at different elevations from lowland at 50 m to montane at 1778 m. Above Ground Biomass (AGB) decreases with elevation: lowland (57.3%), Mid-elevation (25.3%), Submontane (9.7%) and Montane (7.7%), this represent high AGB, carbon, and carbon dioxide pool in RHFR per hectare compared to other sites in Africa (Sonwa et al., 2011). In lowland forest, a mean of 468 t ha^{-1} AGB was higher when compared to some lowland tropical forest with 402 t ha^{-1} (Djuikouo et al., 2010), 404 t ha^{-1} (Lewis et al., 2009), and the Congo Basin forest 429 t ha^{-1} (Lewis et al., 2013). Based on the allometric equation of Chave et al. (2005), which is widely employed to estimate AGB for the past decade (Djuikouo et al., 2010; Memiahge et al., 2016), our 25 ha gave 9993 t with a mean of 400 t ha^{-1} AGB, and 4997 t of carbon with a mean of 200 t ha^{-1}. These values did not change much when compared with a 25 ha plot in lowland forest of Rabi, Gabon, which yielded an AGB of 9235.1 t and a mean of 369.4 t ha^{-1} (Memiaghe et al., 2016). This revealed that the Rumpi Hills forest stores high AGB and carbon on the same surface area as the Rabi plot in Gabon.

In the 17 ha sampled in KFNP, a mean AGB of 194.6 t ha^{-1} (60.7-489.1 t ha^{-1}), and carbon 97.3 tC ha^{-1} (30.4-244.6 tC ha^{-1}) were calculated. These values are far lower compared to the minimum values of AGB (429 t ha^{-1}) and carbon stock estimate of 249 tC ha^{-1} documented previously for Central African forests (Lewis et al., 2013). Although the present study revealed KFNP is poor in mean AGB and carbon, exceptions were observed for some specific plots. For example, plots 1-3 had high mean AGB of 462.2 t ha^{-1} (442.1-489.1 t ha^{-1}), a mean carbon of 231.1 tC ha^{-1} (221.-244.6 tC/ha), which is only slightly lower than values documented by Lewis et al. (2013). In Congo Brazzaville (Iboukikro and Ngambali Forest), a study conducted by Ekoungoulou et al. (2014), in 6 1-ha plot in a gallery forest revealed a mean of 170.7 tC ha^{-1} (99.6-223.2 tC ha^{-1}), which is higher than that of KFNP.

The present study have greatly contributed to understand the biodiversity of Cameroon; a comprehensive checklist of plants of the Rumpi Hills ranging from lowland to montane and in the Kimbi Fungom National Park at different vegetation types were established for the first time. Biodiversity indicators such as forest structure and composition, characterization of the different vegetation types, species diversity, Above Ground Biomass (AGB), carbon and the carbon dioxide sequestered were achieved in the RHFR and KFNP. The above factors will help the government of Cameroon to ratified its international agreements on the Convention of Biological Diversity (CBD), Climate change, REDD, and REDD+.

In Cameroon, studies of montane ecosystems are somewhat scant and even if they exist, the findings of these studies are not easily available to the scientific community (Thomas and Cheek 1992; Thomas and Achoundoung 1994; Achoundoung, 1995; Cheek et al., 2000; Cheek et al., 2004; Forboseh et al., 2011). Thus, this study has set a base for long-term monitoring of the montane ecosystem in Cameroon. Results of this study will help conservation and biodiversity stakeholders in the region to set-up better policies for the proper management of RHFR and the KFNP. This can be achieved by, drawing of management plans, lay down of proper land-use management plan and policies, and set-up different models for ecological monitoring, sustainable agriculture, conservation, education and training.

This study has created awareness on biodiversity and forest inventory in the communities, and during this period over fifteen Cameroonians were trained (students, field assistants, and community members) on forest mensuration, transect cutting, plot establishment, data and specimens collections, plant specimens description, drying, sorting and identification of plot specimens using floras, monographs and herbarium specimens sheets. The creation of a biodiversity database is underway, and this is in addition to scheduled monitoring cycles every five years. The current study is a booster for other scientists and researchers to develop interest in studying other aspects such as soils, climate, forest regeneration and taxa in the RHFR and the KFNP, such as understanding the ecological interaction of plants and other taxa, the effects of climate change, land-use patterns, and other edaphic factors. While this project was a success, there were setbacks that are worth reporting: difficult terrain and topography in some areas hindered the establishment of many plots at high elevation as planned; nevertheless, twenty-five quadrats of 20 x 20 m were established systematically per plot. This study was based on forest inventory only, and lacked data on climate and edaphic factors due to funding constrains.

7.2 RECOMMENDATIONS

- Conserve and protect the natural sites and habitat of the RHFR as much as possible.
- Update the status of RHFR to a sanctuary or a National Park because of its high biodiversity potentials and carbon storage capacity.
- Complete restoration of habitat lost at the KFNP that will enhance climate change.
- Special focus on the Kimbi Fungom Forest to enhance its level of biodiversity, since it's the only national park in the region.
- Implementation of forest, wildlife, andland-use policies; and legislations should be re-enforced at both the RHFR and the KFNP.
- All stakeholders involved in the management of these protected areas should develop a collaborative approach for effective management.
- Scientists and students should be given the opportunity to continue research at the RHFR and the KFNP as multi data layers of different taxa and aspects are necessary.
- Long-term study on the climate, soils, and other future research needs couple with appropriate equipment to study these aspects should be set-up in the RHFR and the KFNP.

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SHORT BIOGRAPHY

Moses Nsanyi SAINGE was born on the 18 of September 1974 in Limbe, Cameroon. He attended the then Saint James College, Ndop between 1985 and 1990, Success Evening School, Tiko between 1991 and 1992, and Government High School, Mundemba between 1992 and 1995. In 2004 he was admitted at the University of Buea to read Botany between 2004 and 2007, He returned to the University of Buea between 2009 and 2012 where he obtained an MSc in Botany at the Department of Botany and Plant Physiology. In 2014 he was granted admission to do a PhD program at the Cape Peninsula University of Technology in Cape Town, South Africa. He carried out his research work on the Cameroon Mountains specifically on Rumpi Hills Forest Reserve and the Kimbi Fungom National Park, Cameroon from February to November, 2015.

Between 1997 and 2004, he assisted in the establishment of the 50 ha permanent plot in central Korup National Park and the establishment of 18 ha of lianas in different capacities: Team Leader, Camp Manager, and Field Manager. Between 2008 and 2009, he led the first re-census of the 50 ha plot in Korup National Park. Between 2012 and 2013, he led the second re-census of trees and first re-census of lianas in the 50 ha plot. Between 2010 and 2015 he established and monitored six hectare plots within 2 km apart from the 50 ha plot for a collaborative research between Center for Tropical Forest Science (CTFS) and the Tropical Ecology and Monitoring Network (TEAM). He served the Center for Tropical Forest Science in Korup National Park, Cameroon for twenty years (1997-2016). His long experience in studying the Flora of Tropical Africa has earned him the Africa specialist for Mycoheterotrophic plants. A study he has been working on for over fifteen years and has discovered and described about seven species new to science (*Afrothismia saingei* Franke, *A. hydra* Sainge & Franke, *A. korupensis* Sainge, & Franke, *A. foertheriana* Franke, Sainge & Agerer, *A. fungiformis* Sainge & Kenfack, *A. pusilla* Sainge & Kenfack and *A.* sp. nov.) and a new genus for Cameroon (*Kihansia jengiensis* Sainge & Kenfack). Beside this, one of the species was named after him (*Afrothismia saingei* Franke). He's much interested and specialized in plant taxonomy, tropical ecology, and biodiversity informatics. He is a co-founder of Tropical Plant Exploration Group (TroPEG) Cameroon. A Non-Governmental Organization where he and his colleagues are trying to understand the forest structure, composition, diversity, carbon stock, and the ecological, livelihood, and ethnobotanical aspect of the Cameroon Mountains through the Cameroon Mountains Biodiversity Project. Between 2011 and 2016, he and his colleagues of TroPEG Cameroon have established 70 permanent 1-ha plots across the Cameroon Mountains: 4 ha at the Mbembe Forest Resreve, 17 ha at the Kimbi Fungom National Park, 12 ha at the Bakossi National Park, 12 ha at Mt Nlonako and 25 ha at the Rumpi Hills Forerst Reserve. In 2013, he was involved with the Biodiversity Informatics

Training Curriculum (BITC) team headed by Prof. A. Townsend Peterson of the Biodiversity Institute, University of Kansas, USA and is currently a Biodiversity Informatics trainer.

Moses Sainge is married to Benedicta Jailughe and has four kids: Elizabeth Sainge Saingi, Thelma Sainge Saingi, Morgan Sainge Saingi, and Carlson Sainge Saingi.

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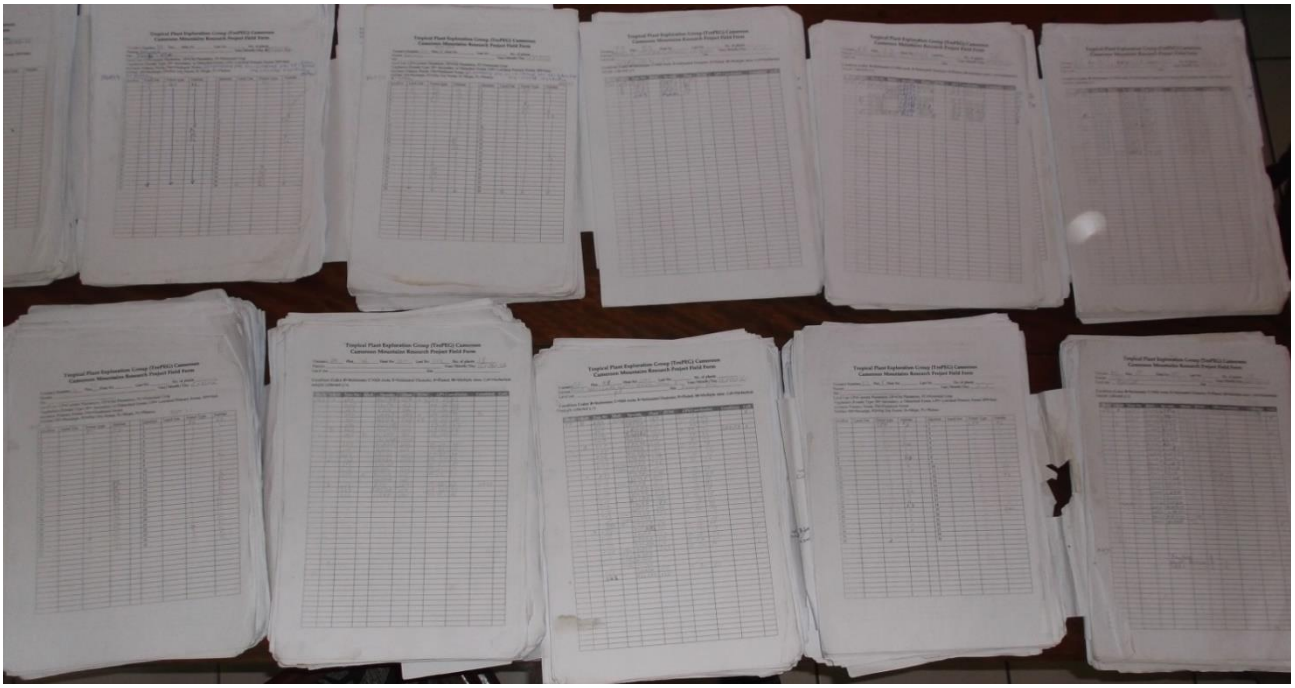
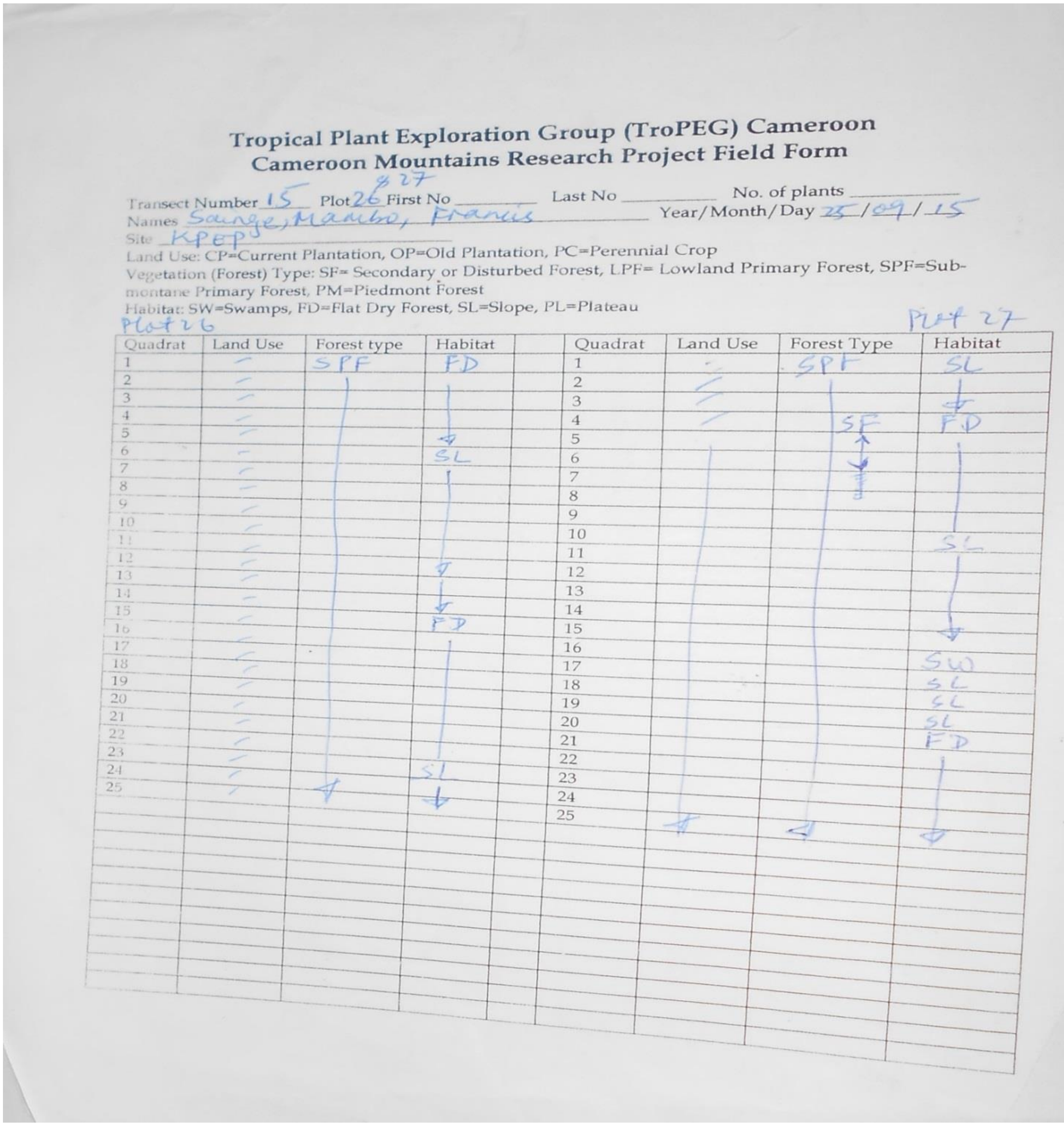
BOOKS

Sainge, M.N. , Lyonga, M. N., Libalah, M. B., Achah, R. A., Fon, J. N., Kenfack , D. and Moudingo, J-Hude E. 2014. Biodiversity Assessment and Conservation Status of Plants in the Mbembe Forest Reserve. Donga Mantung, Northwest Region (NWR), Cameroon. Vol. II, 140pp, ISBN: 978-9956-621-64-4, Tropical Plant Exploration Group (TroPEG) Cameroon.

PLOT DATA



Plot Habitat data form



Tropical Plant Exploration Group (TroPEG) Cameroon
Cameroon Mountains Research Project Field Form

Transect Number 15 Plot 26 & 27 First No ________ Last No ________ No. of plants ________
Names Sange, Mambo, Francis Year/Month/Day 25/09/15
Site KPEP
Land Use: CP=Current Plantation, OP=Old Plantation, PC=Perennial Crop
Vegetation (Forest) Type: SF= Secondary or Disturbed Forest, LPF= Lowland Primary Forest, SPF=Sub-montane Primary Forest, PM=Piedmont Forest
Habitat: SW=Swamps, FD=Flat Dry Forest, SL=Slope, PL=Plateau

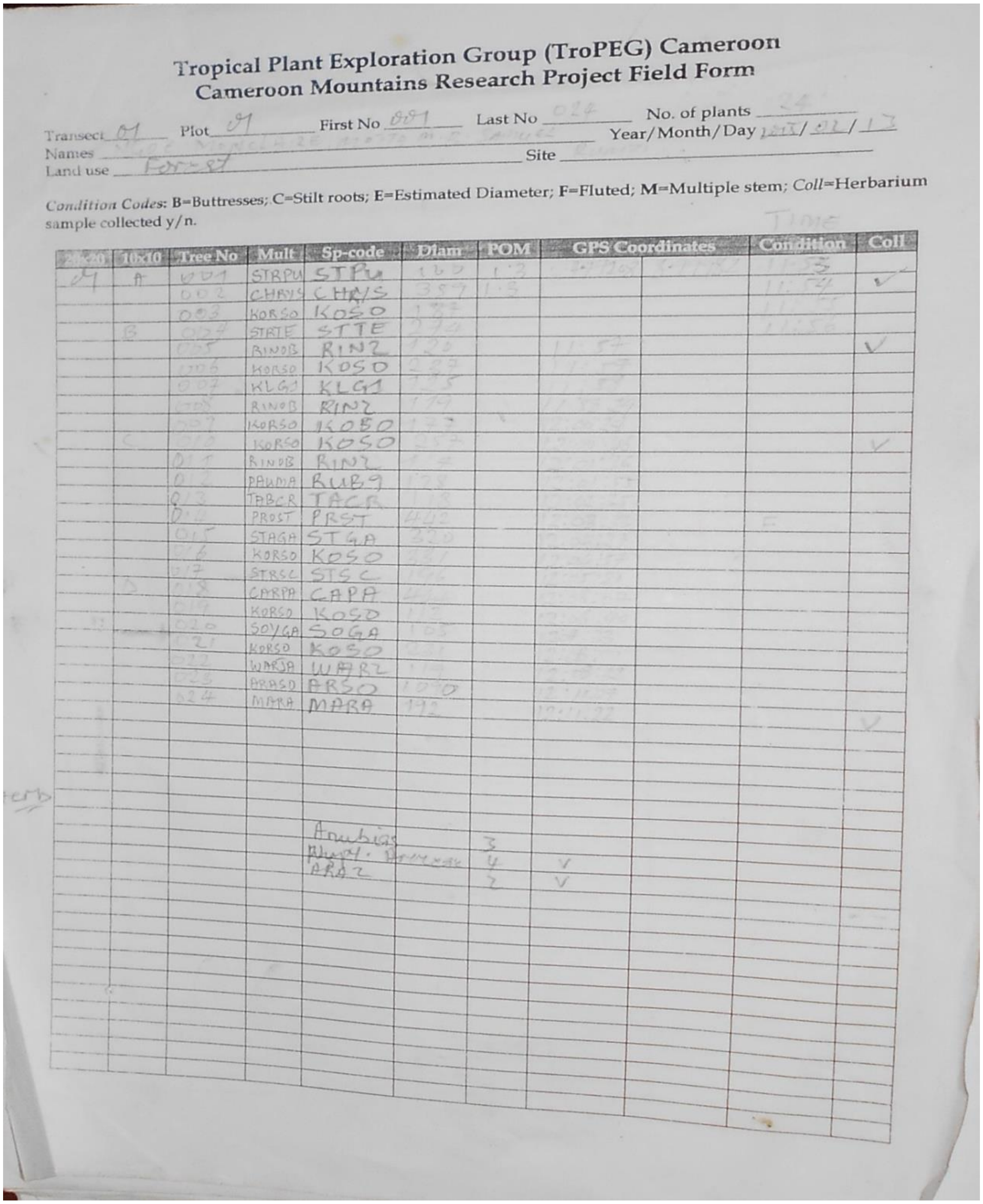
Plot 26

Quadrat	Land Use	Forest type	Habitat
1	–	SPF	FD
2	–		
3	–		
4	–		
5	–		
6	–		SL
7	–		
8	–		
9	–		
10	–		
11	–		
12	–		
13	–		
14	–		
15	–		
16	–		FD
17	–		
18	–		
19	–		
20	–		
21	–		
22	–		
23	–		
24	–		SL
25	–		

Plot 27

Quadrat	Land Use	Forest Type	Habitat
1	–	SPF	SL
2	–		
3	–		
4	–	SF	FD
5			
6			
7			
8			
9			
10			SL
11			
12			
13			
14			
15			
16			
17			SW
18			SL
19			SL
20			SL
21			FD
22			
23			
24			
25			

Plot Main Data Form



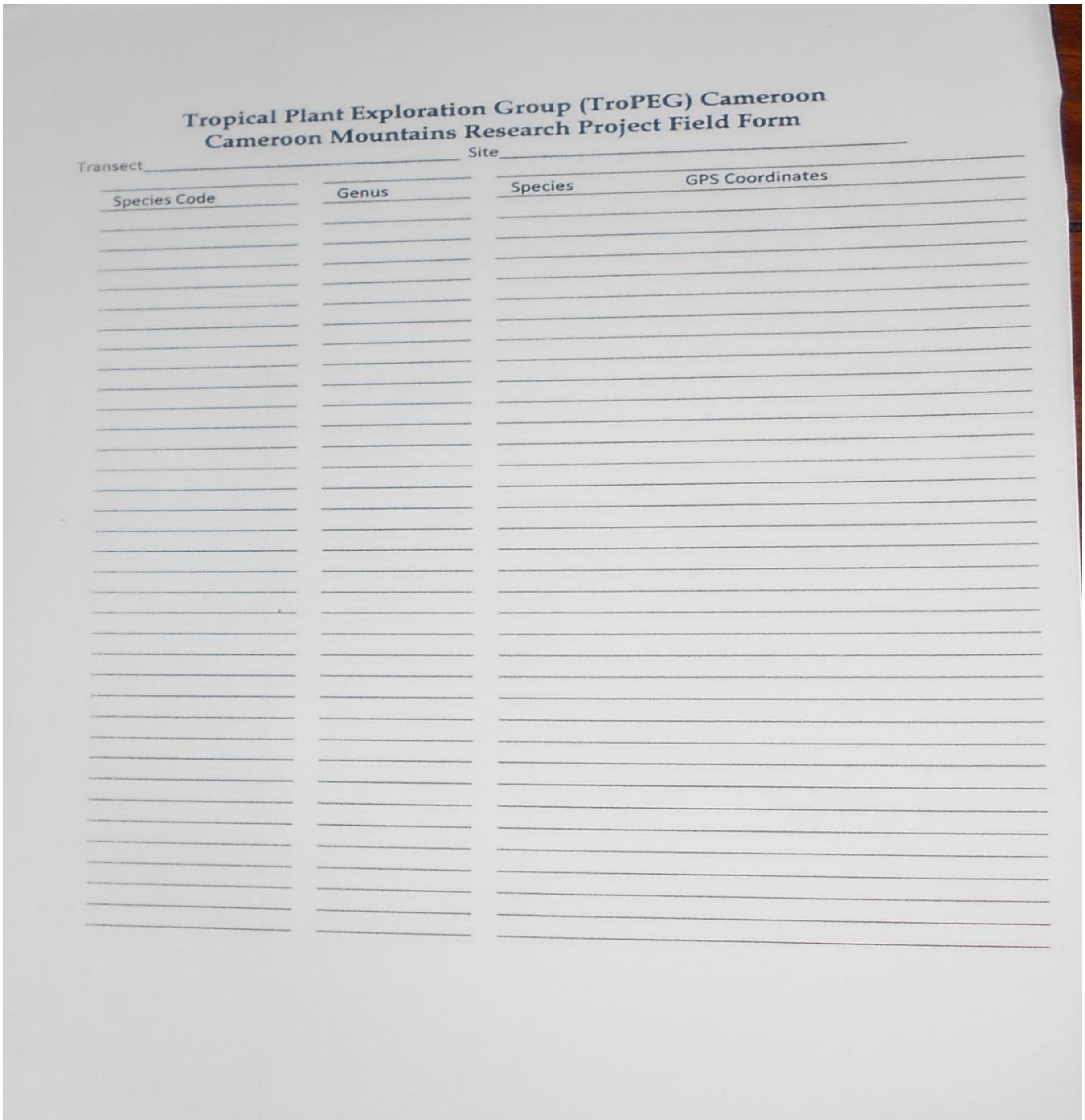
Tropical Plant Exploration Group (TroPEG) Cameroon
Cameroon Mountains Research Project Field Form

Transect 01 Plot 01 First No 001 Last No 024 No. of plants 24
Names [illegible] Year/Month/Day 2013/02/13
Land use Forest Site [illegible]

Condition Codes: B=Buttresses; C=Stilt roots; E=Estimated Diameter; F=Fluted; M=Multiple stem; *Coll*=Herbarium sample collected y/n.

20x20	10x10	Tree No	Mult	Sp-code	Diam	POM	GPS Coordinates	Condition	Coll
01	A	001	STRPU	STPU	160	1.3	[illegible]	[illegible]	✓
		002	CHRYS	CHYS	357	1.3		[illegible]	
		003	KORSO	KOSO	[illegible]			[illegible]	
	B	004	STRTE	STTE	[illegible]			[illegible]	
		005	RINOB	RINZ	120		[illegible]		✓
		006	KORSO	KOSO	[illegible]		[illegible]		
		007	KLGJ	KLG1	[illegible]		[illegible]		
		008	RINOB	RINZ	119		[illegible]		
		009	KORSO	KOSO	177		[illegible]		
	C	010	KORSO	KOSO	257		[illegible]		✓
		011	RINOB	RINZ	[illegible]		[illegible]		
		012	PAUDIA	RUB9	128		[illegible]		
		013	TABCR	TACR	118		[illegible]		
		014	PROST	PRST	442		[illegible]	F	
		015	STAGA	STGA	320		[illegible]		
		016	KORSO	KOSO	331		[illegible]		
		017	STRSC	STSC	196		[illegible]		
	D	018	CARPA	CAPA	[illegible]		[illegible]		
		019	KORSO	KOSO	112		[illegible]		
		020	SOYGA	SOGA	105		[illegible]		
		021	KORSO	KOSO	231		[illegible]		
		022	WARJA	WARZ	119		[illegible]		
		023	ARASO	ARSO	1090		[illegible]		
		024	MARA	MARA	192		[illegible]		
				Anubias		3			
				Aloe? [illegible]		4	✓		
				ARA2		2	✓		

Observational Data Form



Tropical Plant Exploration Group (TroPEG) Cameroon
Cameroon Mountains Research Project Field Form

Transect__________ Site__________

Species Code	Genus	Species	GPS Coordinates

PERMITS

Ministry of Scientific Research and Innovation (MINRESI)

REPUBLIQUE DU CAMEROUN
Paix-Travail-Patrie

MINISTERE DE LA RECHERCHE SCIENTIFIQUE ET DE L'INNOVATION

SECRETARIAT GENERAL

DIVISION POLITIQUES SCIENTIFIQUES ET DE LA PLANIFICATION

CELLULE DE LA PROGRAMMATION ET DE LA PLANIFICATION

B.P : 1457 Yaoundé – Cameroun
Tél : (237) 22 22 13 34 ou 22 22 52 02

…PUBLIC OF CAMEROON
Peace-Work-Fatherland

…ENTIFIC RESEARCH AND INNOVATION

…NERAL SECRETARIAT

…CIENTIFIC POLICY AND PLANNING

PROGRAMMING AND PLANNING UNIT

PO Box 1457 Yaounde Cameroon
Tél : (237) 22 22 13 34 or 22 22 52 02

N° 005 /MINRESI/B00/C00/C10/C11

Yaoundé, le 06 FEV 2015

AUTORISATION DE RECHERCHE
RESEARCH PERMIT

Vu la Constitution ;
Mindful constitution ;
Vu le décret n°2011/408 du 09 décembre 2011 portant organisation du Gouvernement ;
Mindful of decree n°2011/408 of 09 December 2011 organizing the Government;
Vu le décret n°2011/410 du 09 décembre 2011 portant formation du Gouvernement ;
Mindful of decree n°2011/410 of 09 December 2011 appointing the members of the Government
Vu le décret n°2005/091 du 29 mars 2005 portant organisation du Ministère de la Recherche Scientifique et de l'Innovation ;
Mindful of decree n°2005/091 of 29 March 2005 organizing the Ministry of Scientific Research And nnovation;
Vu la demande de l'intéressé .
Considering the Applicant's request.

Noms et prénoms/ *Names* : SAINGE Nsanyi Moses

Adresses Permanentes/ *Permanent address* : Tropical Plant Exploration Group (TroPEG) P.O. Box : 18 Mundemba, Ndian Division. Southwest Region Cameroon, email : sainge2001@yahoo.com, moses.sainge@gmail.com.

Adresse au Cameroun / *Address in Cameroon*: Dr FOKAM Eric Bertrand Enseignant-Chercheur Université de Buéa Département de Zoologie, B.P 63 Buea Tel. 677920739, email : efokam@daad-alumni.de.

Nationalité / *Nationality* : camerounaise

Est autorisé (e) à effectuer des travaux de recherche en République du Cameroun dans la ou les Region(s) de: *Is hereby authorized to carry out scientific or technical research in the Republic of Cameroon in the Region of:*
Sud-Ouest et Littoral

Pour une période de / *For a period of* : 05 mois du/ from : 30/01/2015 au/to 30/06/2015

En collaboration avec / *In collaboration with* : s/c Dr FOKAM Eric Bertrand Enseignant-Chercheur Université de Buéa Département de Zoologie, B.P 63 Buea Tel. 677920739, email : efokam@daad-alumni.de.

Objet de la Recherche/ *Research Title* : Biodiversity Patterns and Climate effects in the Cameroon Mountains.

Cette autorisation de recherche n'est valable que pendant la période de recherche indiquée ci-dessus, et peut être renouvelable. *This research permit is valid only for the research period indicated above and it can renewed.*

AMPLIATION:
CAB/MINRESI
SGPRC
SGPM
MINDEF
DGSN
DGRE
CRRI – Sud-Ouest et Littoral
SG/MINRESI
IG/MINRESI
C/DPSP

Pour le Ministre de la Recherche Scientifique et de l'Innovation
et par délégation
Le Secrétaire Général

Mme EBELLE ETAME
Rebecca Madeleine

Ministry of Forestry and Wildlife (MINFOF)

REPUBLIQUE DU CAMEROUN
Paix-Travail-Patrie

MINISTERE DES FORETS
ET DE LA FAUNE

SECRETARIAT GENERAL

DIRECTION DE LA FAUNE
ET DES AIRES PROTEGEES

BP : 34430 Yaoundé
Tel : 222 23 92 28

REPUBLIC OF CAMEROON
Peace-Work-Fatherland

MINISTRY OF FORESTRY
AND WILDLIFE

SECRETARIAT GENERAL

DEPARTMENT OF WILDLIFE
AND PROTECTED AREAS

Yaoundé, le 17 MARS 2015

N° 1507 /L/MINFOF/SG/DFAP/SDVEF/SC/MBA
Ref : V/L du 12 février 2015

LE MINISTRE

A

Monsieur Moses Nsanyi SAINGE
TropPlant Exploration Group (TroPEG)
POBox 18 Mumdemba, Ndian Division,
South-West Region Cameroon
Email: saigne2001@yahoo.com
Moses.saigne@gmail.com
Cell.+237 677 92 07 39

Objet : Demande d'une autorisation de recherche

Monsieur,

Comme suite à votre lettre susvisée, relative à l'objet repris en marge,

J'ai l'honneur de vous marquer mon accord de principe pour mener vos travaux de recherche sur le thème : *«Biodiversity Patterns and climate effects in the Cameroon Mountains»* dans les écosystèmes de montagne des Régions du Sud-Ouest, du Nord-Ouest et du Littoral durant la période d'un (01) an à partir de la date de signature de la présente autorisation, dans les sites de Rumpi hills, Mont Nlonako et le Parc national de Kimbi-Fungom.

Veuillez agréer, Monsieur, l'expression de ma considération distinguée.

Copies :
DR MINFOF-SW
DR MINFOF-LT
DR MINFOF-NW

République du Cameroun / Republic of Cameroon – Le Ministre / The Minister – Ministère des Forêts et de la Faune / Ministry of Forestry and Wildlife

Ngole Philip Ngwese

Letter of Authorization from Fon of Esu

REPUBLIC OF CAMEROON
Peace – Work – Fatherland

MINISTRY OF TERRITORIAL ADMINISTRATION AND DECENTRALIZATION

NORTH WEST REGION

MENCHUM DIVISION

FUNGOM SUB-DIVISION

ROYAL PALACE, ESU FONDOM

Tel: (237) 96 75 07 55 / 77 24 58 50

REPUBLIQUE DU CAMEROUN
Paix – Travail – Patrie

MINISTERE DE L'ADMINISTRATION TERRITORIALE ET DECENTRALISATION

REGION DU NORD OUEST

DEPARTEMENT DE LA MENCHUM

ARRONDISSEMENT DE FUNGOM

CHEREFIE D'ESU

Tel: (237) 96 75 07 55 / 77 24 58 50

REF N°. ______________

DATE: 22 SEPT 2015

To,

WHOM IT MAY CONCERN.

The bearers of this Note by Names:-
1 Forestry officer MEH KENNATH GEH,
2 SAINGE NSANYI MOSES,
3 NJOM ENE MANFRED,
4 OSENG KWELLE,
Are researchers authorised by the Minister of forestry and Wildlife to explore the KIMBI-FUNGOM NATIONAL PARCK. They have officially presented themselves to this palace.
You are therefore call upon to assist them when and wherever the need arises.
Thanks in advance for your understanding and Co-operation.

REPUBLIC OF CAMEROON – FUNGOM SUBDIVISION – ESU FONDOM – MENCHUM – NORTH WEST

His Majesty Fon Kum-a-Chuo II
Kawzu Albert
FON OF ESU

Photographs of study sites