Road edge effect on Forest Canopy structure and Epiphyte biodiversity in a Tropical Mountainous Rainforest, *Nyungwe National Park, Rwanda.*

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Road edge effect on forest canopy structure and epiphyte biodiversity in a Tropical Mountainous Rainforest,
Nyungwe National Park, Rwanda.

By

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Abstract

Tropical Rainforests are home to two-thirds of all living animal and plant species on the planet. Over 70 % of the forest biological information is related to the forest canopy, home to a unique flora and fauna not found in other layers of a forest. However, tropical rainforest canopies are threatened by human activities such the road networks which create gaps, divide the ecosystem and create structural edges. As such, the spatial examination of road edge effects is required to understand changes induced by road networks on ecosystems. Thus, this study evaluated and mapped the effects of road edges on forest canopy structure and epiphyte biodiversity in the tropical mountain rainforest of Nyungwe National Park in the South-west of Rwanda. We used ANOVA and ANCOVA to assess depth of road edge effects for canopy cover, canopy height and canopy vascular epiphyte presence and abundance. Using several environmental parameters we applied logistic regression and path analysis to assess the net impact of road edges on vascular epiphyte occurrence. Spatial patterns of impacts on vascular epiphyte distribution were mapped by relating presence/absence data to the spectral information of Aster imagery.

The results indicated that there is a significant gradient for canopy cover and height and canopy vascular epiphyte occurrence. Along paved roads, we detected a highly significant gradient ($p<0.001$) for all parameters and insignificant gradient along secondary roads ($p>0.05$ for all distances). That confirms the statement from previous research which revealed that road width was found to be a significant factor determining the road edge effect. Based on the most accurate logistic model assessed by the residual deviance information (72.2), AIC (86.2) and ROC curve (0.95 AUC); the probability of vascular epiphytes to occur was predicted (at 95% of accuracy). Spatial models using spectral information explained 77% of vascular epiphytes to occur. That was not surprising considering the gradient width as compared to the spatial resolution of the Aster image and given the heterogeneity in canopy biophysical characteristics of Nyungwe rainforest.

The depth of the road edge effect and its direct and indirect impact on vascular epiphytes were successfully delineated and could have cumulative effects on forest canopy structure and biodiversity. Such changes deserve attention during planning, design and maintenance by local roads managers and officials in charge of national parks.

Keywords: Tropical rainforest; Impact gradient; Canopy cover; Canopy height, vascular epiphyte, modeling.

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List of abbreviations

AIC: Akaike Information Criterion
ANOVA: Analysis of variance
ANCOVA: Analysis of covariance
A.s.l: above sea level
ASTER: Advanced Space-borne Thermal Emission and Reflection Radiometer
ATCOR: Atmospheric Correction of satellite data
AUC: Area under Curve
CGIS – NUR: Geographic Information Systems and Remote Sensing Training and Research Centre of National University of Rwanda.
DEM: Digital Elevation Model
ENVI: The Environment for Visualizing Images
FAO: Food and Agriculture Organization of the United Nations
GAM: Generalised Linear Models
GCP: Ground Control Points
GLA: Gap Light Analyzer
GLM: Generalized Linear Model
GoR: Government of Republic of Rwanda
ILWIS: Integrated Land and Water Information System software
IRST: Institut des Recherches Scientifiques et Technologiques
ITC: International Institute for Geo-Information Science and Earth Observation
JPEG: Joint Photographic Experts Group
Landsat ETM: Land Remote Sensing Satellite Enhanced Mapper Data
Landsat TM: Land Remote Sensing Satellite Thematic Mapper Data
MININFRA: Ministry of Infrastrucutres
MINITERE: Ministry of Land, Environment, Forestry, Water and Mines
OLS: Ordinary least square
ORTPN : Office Rwandais du Tourisme et des Parcs Nationaux
PCFN : Projet Conservation de la Forêt de Nyungwe
RD: Residual Deviance
ROC: Receiver Operating Characteristic Curve
SPOT: Satellite Pour l'Observation de la Terre
SPSS: Statistical Package for the Social Sciences software
SWIR: Short-Wave Infrared
TSI: Terrain Shade Index
UNEP: United Nations Environment Programme
UTM: Universal Transverse Mercator
VNIR: Visible and Near Infra Red
WCS: Wildlife Conservation Society
WWF: World Wildlife Fund

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1. Introduction

1.1. Background and Significance

1.1.1. Tropical rainforest

World terrestrial ecosystems are classified into two fundamentally different ways: (i) into biomes, defined by the dominance of particular plant functional types; (ii) into biogeographically regions, based on the distribution of plant and animal taxa. Rainforests are characterized by a gigantic amount of rainfall with minimum annual rainfall of 1750 to 2000 mm per annum (Richards 1979), but there are various definitions of tropical rainforest (Pears 1968; Green 1980; Gell and Mercer 1992). According to the World Wildlife Fund biome classification scheme (WWF 2007), tropical rainforests are considered a type of ’tropical wet forest’ or ’tropical moist broadleaf forest’ and may also be referred to as “lowland equatorial evergreen rainforests”.

Considering the biophysical condition, tropical and subtropical rainforest has different subgroups. Ecologists group them in four main categories (Richards 1996; Whitmore 1998; Butler 2005): (1) Lowland equatorial evergreen rainforest; (2) Moist deciduous and semi-evergreen forests; (3) Mountain rainforests, some of which are known as Cloud forests, (4) Flooded forests, including freshwater swamp forests and peat swamp forests. A rainforest is divided into five different layers (Wu, Tsui et al. 2007) namely the Emergent layer, Canopy layer, Understory layer, Shrub Layer and Forest floor.

The ***canopy*** is the uppermost level of a forest formed by the tree crowns. The uneven layers of the canopy is formed by both dominant and co-dominant trees. Tree height, tree cover and tree spacing are the main attributes of canopy structure (McElhinny, Gibbons et al. 2005). Intact primary tropical rainforest canopy is typically 10m thick (Figure 1A), and intercepts around 95% of sunlight. Such conditions favour unique flora and fauna which is not often found in other layers of a forest. Over 70 % of epiphyte, insects, primates, birds and snakes among others biological information life in the rainforest is related to the canopy (Lowman and Wittman 1996). William Beebe (1917) referred to is as “another continent of life undiscovered”. Rainforests are home of two-thirds of all the living animal and plant species on the planet.

Rainforest also play a major role in the global carbon cycle as stable carbon pools (Malhi 2002; Glenday 2006), they also cool air that passes through them (Weber 1959; Dykes 2000) creating favorable conditions for life elsewhere. As such, rainforests are of vital importance within the global climate system. Likewise, the rainforest provides a multitude of resources for local indigenous people including food and shelter (Reitz 2001; Willcox and Nambu 2007). A number of plants found in the rainforest can also be used for medicinal purposes.

However, tropical rainforests, 15 % of the global tropical forests (see chart in figure 1B), are highly threatened. The FAO estimates that about 13.5 million hectares of tropical rainforest are destroyed permanently per year (FAO 2001). Roads construction and traffic are ones among important causes of deforestation (Boletta, Ravelo et al. 2006).

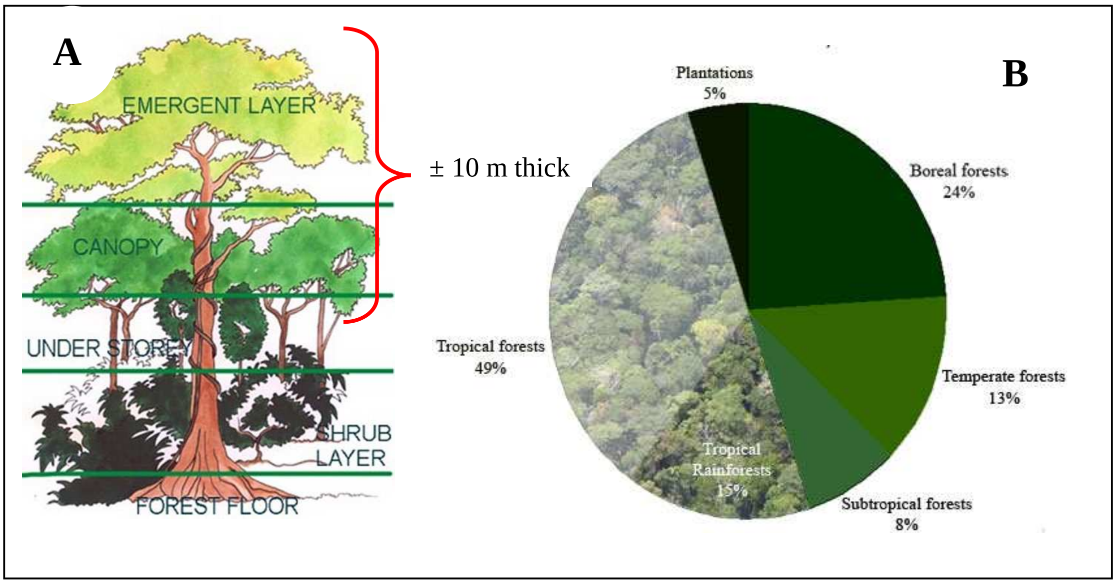


Figure 1: Tropical rainforest proportion and its forest canopy structure/layers visualisation

Figure 1**A** shows five layers of rainforest strata; canopy height or canopy thickness is a function of cover and height of understory, tree/canopy and emergent. The Chart in Figure 1**B** shows the percentage cover of world forests. Rainforests are a subsection of tropical forests (FAO 2007; Rainforestlive 2007).

1.1.2. Road edge effect on canopy structure and Epiphyte biodiversity

Edge effects (alterations to habitat quality due to proximity to the edge) are a central influence over local biotic and abiotic processes in the forested area (Kent and Coker 1992; Zartman and Nascimento 2006). Thus, edge penetration distances for most vegetation structure variables are greater at open edges than at closed edges. The magnitude of these differences suggests that the edge structure is one of the main determinants of the vegetation structure within tropical forest fragments (Didham and Lawton 1999 ; Schedlbauer, Finegan et al. 2007).

Roads play a key role in human movement over the land and they connect societies and economies. In tropical areas, some roads are often explicitly designed for access to access natural: mining sites (Hilson 2002), logging (Iskandar, Snook et al. 2006) and oil (Forman and Alexander 1998; Hill and Curran 2001). Governments and development agencies fund projects to develop road networks in tropical rainforests (UNEP 2002; Tanner and Perry 2006). Conversely, the development of road networks in forests creates gaps and it divides the ecosystem resulting into structural edges (Glenn, Webb et al. 1998; Ali, Benjaminsen et al. 2005; Delgado, Arroyo et al. 2007). As such great forests are increasingly chopped into smaller blocks leading to habitat loss for the multitude of species that inhabit the forests (Lindenmayer, Franklin et al. 2006).

In forest ecosystems, forest cover dominates the landscape, but roads remove or disturb large areas through direct and indirect abiotic and biotic change (Watterson and Jones 2006). The resultant crown cover and height disturbances extend beyond the initial edge limit. Furthermore, numerous exotic plants are increasingly colonizing forest road edges due to the microclimatic changes produced in the zone (Enserink 1997). Regarding native species, their habitat is fragmented and the degree of endemism decreases (Cordeiro, Burgess et al. 2007).

In tropical rainforests the ecological edge effects of roads are causing higher loss of biodiversity than the expected by environmental managers. The threatened flora includes epiphyte, orchids, bromeliads, mosses, and lichens, which live attached to the branches of trees (Lowman and Wittman 1996).

Vascular epiphyte are plants that grow on other plants, upon which they are dependent for mechanical support, but not for nutrients**.** Epiphytes make up about 10% of all vascular plant species worldwide and they are almost exclusively found in tropical forests. Therefore, they constitute a large part of the global plant biodiversity (Piazzi, Acunto et al. 2000) and in tropical countries they represent up to 25% of all vascular plant species (Nieder, Prosperí et al. 2001). Being highly sensitive to human disturbance, they are considered as bio-indicator of disturbance from physical conditions (Sim-Siam, Carvalho et al. 2000).

Studies focusing on impacts of the road edge on a specific biophysical parameters include reptiles distribution (Tanner and Perry 2006; Row, Blouin-Demers et al. 2007); great apes (UNEP 2002) and invasive species (Hansen and Clevenger 2005; Watterson and Jones 2006). In such studies statistical models are often used to identify the distance along transects (perpendicular to roadside) over which the edge effects were significant. Among the findings so far is the fact that canopy gap size is positively correlated biodiversity loss or disturbance. As such, canopy structure is a reliable proxy for assessment of the ecological impacts of roadside to biodiversity. Due to difficulties associated with sampling the crowns of large canopy trees in large inaccessible regions, biological information about canopies in tropical forest is inadequate. Therefore recent advancements applications of remote sensing are often utilised to provide such information (Myers, Newton et al. 2000; Chambers, Asner et al. 2007). Using spectral information and identifying the most correlated vegetation indices could provide a surrogate and quantitative measure of biophysical properties (Major, Baret et al. 1990; Castro-Esau, Sanchez-Azofeifa et al. 2004; Kalacska, Sanchez-Azofeifa et al. 2007).

Vegetation indices resulting from differentiation, rationing and orthogonalisation of different sensor bands are prominent in biophysical properties modelling of terrestrial forests (Song and Woodcock 2002; Roberts, Keller et al. 2003; Koetz, Sun et al. 2007). However only a few studies on vascular epiphyte are available and the potential for remote sensing in their prediction are yet to be considered by a scientific study.

1.1.3. Rainforest in Rwanda

The natural ecosystems of Rwanda are mainly composed of mountain rainforest. They comprise of Nyungwe National Park, Mukura natural forest, Gishwati natural forest and Volcanoes National Park. These ecosystems are part of the Albertin rift afro-mountain forest and they constitute an important habitat for biodiversity and ecosystem services (MINITERE/RWANDA 2003). Their flora and fauna include several species of birds and primates. A high percentage of these species are endemic (Plumptre, Davenport et al. 2007). However, rainforests in Rwanda are undergoing rapid environmental degradation and change following accelerated deforestation for settlement and road construction as well as, soil erosion. Within the past 40 years, protected areas in Rwanda have decreased by more than 50% as clearly shown by figures in Table 1 below. The deforestation is primarily due to population pressure.

Table 1: Extent of Rwandan rainforest over time (area in ha)

	1960	**1970**	**1980**	**1990**	**1996**	**2000**
Nyungwe National Park	130 000	108 000	97 500	97 000	97 000	97 000
Mukura forest	3 000	3 000	2 100	2 100	1 600	1 200
Gishwati forest	28 000	28 000	23 000	8 800	3 800	600
Volcanoes National Park	34 000	16 000	15 000	12 760	12 760	12 500

Source: (Gatera 2001)

The extents of the Volcanoes and Nyungwe National Park have been stabilized from two decade due to governmental intervention. But illegal activities within the park boundaries by the surrounding population increases with population growth. Communities living around them have traditionally benefited from a variety of wood and non-wood forest products such as honey, bamboo, natural ropes, medicinal plants, water, wood fuel and others (GAPUSI 1999). Rwandan Office of Tourism and National Park (ORTPN) recognized this challenge and attempts to include community participation in conservation, awareness-raising and tourism-revenue sharing amongst their top priorities. The access into the park is limited to ecotourism activities. Through ecotourism the park’s biodiversity is preserved while also making a significant contribution to the national economy and the enhancement of off-farm employment.

However, Nyungwe rainforest is still threatened by human presence. Out of recent ecotourism activities, large number of population access into the forest due to the presence of main and secondary public roads through the forest. Thus, after several studies on how human density and infrastructure development affect endemic and threatened species in Albertin rift ecosystems (Bergl, Oates et al. 2007; Burgess, Balmford et al. 2007; Plumptre, Davenport et al. 2007), Conservation International (CI) has recognized Nyungwe rainforest as part of the Eastern Afromontane Hotspot in its global analysis (Cordeiro, Burgess et al. 2007)

1.2. Problem statement and justification

1.2.1. Research problem

Microclimate and biotic change caused by road edges creates suitable conditions for exotic or sun loving native species (Arevalo and Fernandez-Palacios 2000). Furthermore, shrubs and herbs colonize narrow open roadsides previously covered by trees (Ali, Benjaminsen et al. 2005). These factors affect the epiphyte species by the tree disturbances and microclimatic change. Long-term effects of road edges are also related to characteristics of the roads like width of cleared area, road surface: tarmac, gravel, dust, etc. (Laurance 1991; Hansen and Clevenger 2005).

A 135 km of national paved road connecting South and Western provinces and Rwanda to Bukavu (Eastern region of D.R of Congo) has a section of 52 km through Nyungwe mountain rainforest. The socio-economic importance at national and regional level of that road ensures its high traffic intensity. Nyungwe National park is also intersecting with around 100 km of minor roads (unpaved). The most important is the *Pindura – Bweyeye* road which crosses the south-western part of the forest (figure 5). Both roads were constructed in 1930's by the Belgian colonial administration and the main road was paved in 1980. The roads in a steep forested landscape like Nyungwe increase biophysical processes (Watterson and Jones 2006). As such the environmental changes generated by interactions between geomorphologic and biogeographic processes are important (summarized by a conceptual diagram in figure 2).

From 1980's some inventories of fauna and flora were undertaken by local and international researchers within Nyungwe forest (Plumptre, Masozera et al. 2002). Furthermore emphasis was on tree phenology and primate ecology. Until now, epiphyte are poorly surveyed (Plumptre, Davenport et al. 2007). This creates a need to quantify and map the forest structure and biodiversity loss from the existing roads network.

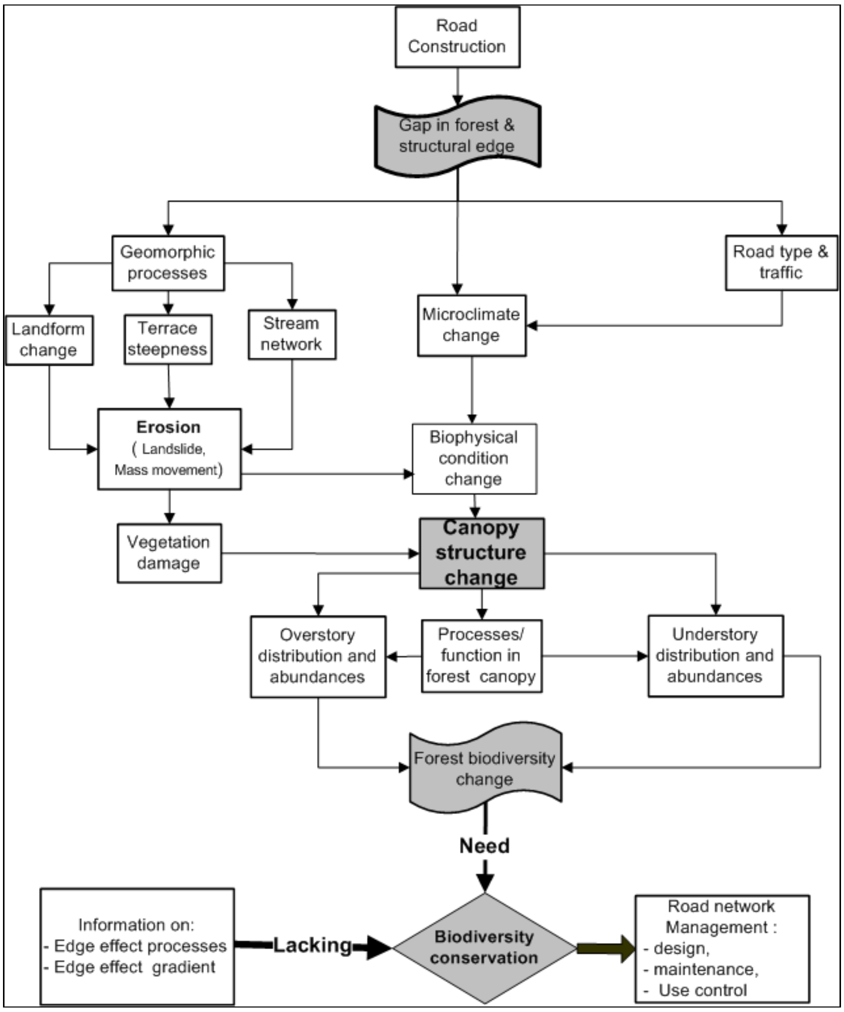


Figure 2: Processes and factors of impact of road edge in mountain rainforest

1.2.2. Research justification

Rwanda conservation authorities believe in the role of new knowledge generated by research for development of conservation strategies. But environmental research output is still few.

One unpublished document has pointed the abnormal presence and abundances of *Hagenia abyssinica*, *Macaranga sp*., *Pteridium acquilinum* (Rizinjirabake 2002). Canopy cover and its biodiversity disturbance should be more representative indicators of road edge effect in Nyungwe tropical and mountain rainforest. Epiphyte diversity in Nyungwe is very high and more than 100 species of orchids and several new species are still unidentified in the area (Fischer 1997).

The research findings on "Road edge effect on forest canopy cover and Epiphyte biodiversity" will be an important contribution on ecologically sustainable forest management. It will provide a scientific reference point for the development of policies on the use and maintenance of existing road infrastructure within the park. Since, ecotourism has been selected as one among priority sectors "for economic growth and conservation of biodiversity", by the government of Rwanda in its vision 2020 goals, this study will contribute to the design and implementation of new roads or tourism trails (Pickering and Hill 2006) and other ecotourism infrastructures within Nyungwe National Park area.

1.3. Research objectives

The main objective is to evaluate and map the effects of the road edges on forest canopy structure and epiphyte biodiversity in the tropical mountainous rainforest of Nyungwe National Park in the South-west of Rwanda.

The specific objectives include:

1) To assess canopy cover, canopy height and vascular epiphyte biodiversity gradient from paved and secondary roads to the forest interior;
2) To determine the best environmental and spectral predictors for vascular epiphyte presence in the canopies.
3) To develop and calibrate a spatial model that estimates the gradient in the occurrence of canopy vascular epiphytes.

1.4. Research questions

1) To what extend road edges affects canopy cover; canopy height and vascular epiphyte biodiversity?
2) Is the relationship between road type and edge effect on canopy cover, canopy height and vascular epiphyte biodiversity significant?
3) Which independent variables best predict the gradient of canopy vascular epiphyte distribution?
4) Which spatial model can enhance the assessment of the gradient of the road edge effect on canopy vascular epiphyte biodiversity?

1.5. Hypotheses

1) Hypothesis 1

Ho: There is no significant difference in the canopy cover, canopy height and vascular epiphyte biodiversity in relation to distance from the road in Nyungwe tropical mountain rainforest.

Ha: There is an abrupt change in canopy cover, canopy height and vascular epiphyte biodiversity in relation to distance from the road in Nyungwe tropical mountain rainforest.

2) Hypothesis 2

Ho: There are no significant differences between gradients of canopy cover, canopy height and vascular epiphyte biodiversity along paved and secondary road in Nyungwe tropical mountain rainforest.

Ha: There are significant differences between gradients of canopy cover, canopy height and vascular epiphyte biodiversity along paved and secondary road in Nyungwe tropical mountain rainforest.

3) Hypothesis 3

Ho: Canopy vascular epiphyte distribution is not a function of the forest canopy structure in Nyungwe tropical mountain rainforest.

Ha: Canopy vascular epiphyte distribution is a function of the forest canopy structure in Nyungwe tropical mountain rainforest.

4) Hypothesis 4

Ho: There is no positive association between medium resolution image information and gradient in canopy vascular epiphyte biodiversity along roads in Nyungwe tropical mountain rainforest.

Ha: There is positive association between medium resolution image information and gradient in canopy vascular epiphyte biodiversity along roads in Nyungwe tropical mountain rainforest.

1.6. Assumptions

The main assumption made is that “canopy structure (cover and height as component) and vascular epiphyte diversity (canopy biodiversity category) are interrelated and reliable indicators of tropical rainforest disturbance from road edge”. Therefore, some terms and concepts need to be defined before developing methodology.

1.6.1. Epiphyte and vascular epiphyte

An epiphyte is an organism that grows upon or attached to a living plant. Epiphytic plants use photosynthesis for energy and (where non-aquatic) obtain moisture from the air or from dampness (rain and cloud moisture) on the surface of their hosts. Epiphytic plants attached to their hosts high in the canopy have an advantage over herbs restricted to the ground where there is less light (Nieder, Prosperí et al. 2001). The best-known epiphytic plants include *mosses, orchids* and *bromeliads.* Assemblages of large epiphyte occur most abundantly in moist tropical forests, but mosses and lichens occur as epiphyte in almost any environment with trees. ***Vascular epiphyte*** is epiphyte with a dedicated transport system for water and nutrients like orchids and bromeliads (Alan R. Smith and Wolf 2006) and occurs in tropical conditions.

1.6.2. Holo-epiphytic and hemi-epiphytic

Holo-epiphytic plants are the typical epiphytic plants that live a non-parasitic life only on a host tree throughout their lives. Hemi-epiphytic plants however live epiphytic life until their aerial roots have connected to the ground. In this study, ‘**holo-epiphytic’** plants are of concern since these were the plants that got our attention during field work. Other group should induce confusion with lianas, parasite and other canopy life species.

1.6.3. Epiphyte habitat requirement

Vascular epiphyte prefers where physiological conditions are secured. High light intensity and air humidity and no danger of frost dryness occurs are the key factors (Nieder, Prosperí et al. 2001). Nutrient content from leaf litter and woody debris has to be sufficient. Therefore, epiphyte diversity and abundance are positively correlated to the successional stage of a forest (Gentry and Dodson 1987).

1.7. Research approach

Demarcation of road edge effects on forest canopy structure and vascular epiphyte require the best discriminating methods of variance from road edges to the forest interior (as summarized by figure 3). In order to investigate the spatial pattern of the road edges effect on tropical rainforest, all potential environmental predictors have to be collected, analysed and mapped using GIS and RS software. Therefore, this study followed three main steps: (1) Relevant information on biophysical condition, epiphyte autecology and epiphyte species presence were collected. (2) Image and vectors datasets were also collected and preprocessed before field work activities. During September 2007, field data were collected in the study area and followed by (3) Statistics and spatial analysis. ANOVA tests with contrast procedures proved to be useful (Jay 1998; Eigenbrod, Hecnar et al. 2008). Vascular epiphyte presence and abundance in relation to distance from road must involve covariance analysis (ANCOVA).

Regression modelling using environmental and RS data were integrated to assess direct and indirect effects of the road on forest structure and epiphyte biodiversity and visualise the spatial distribution of vascular epiphyte.

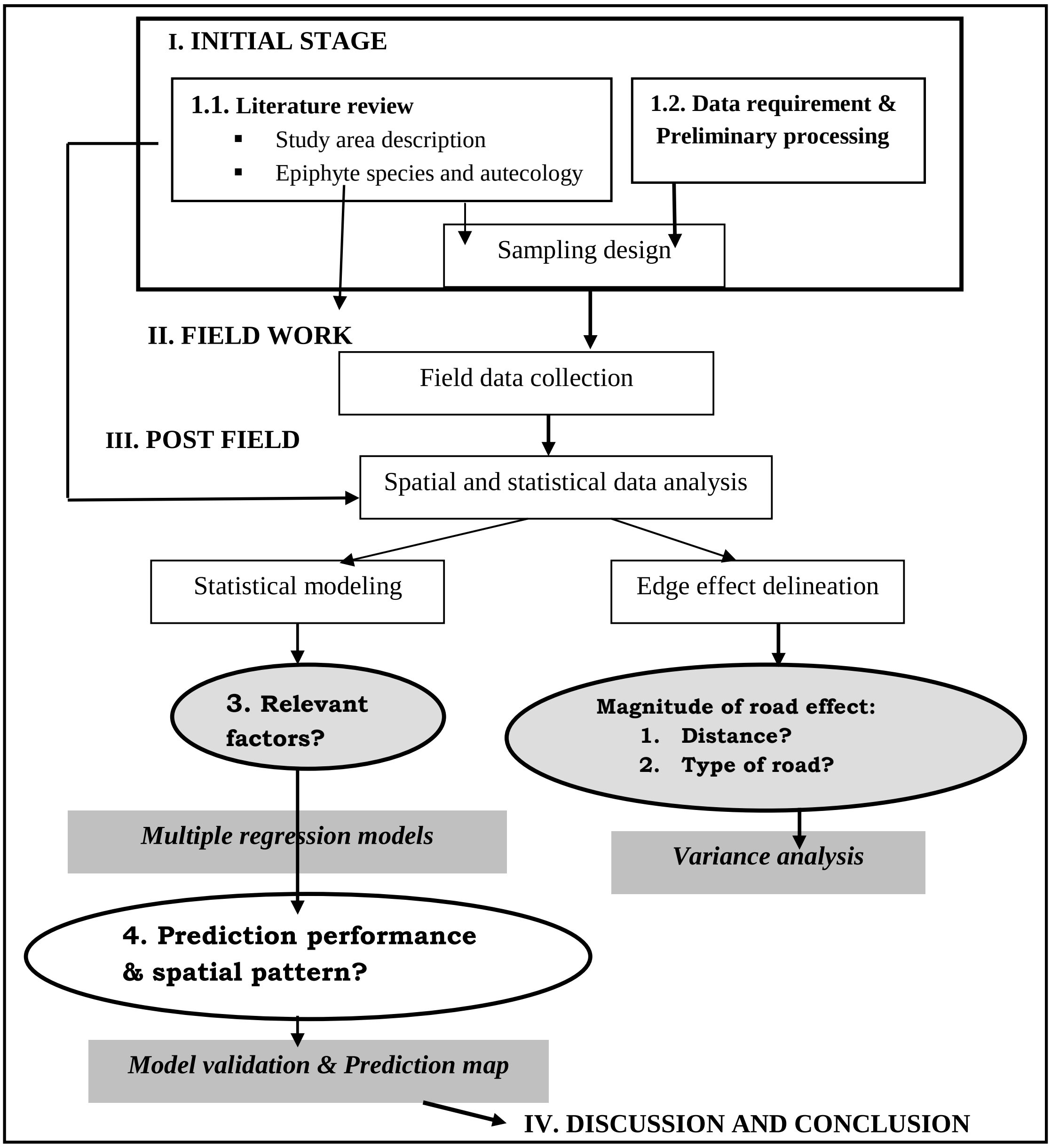


Figure 3: Decision tree summarizing approach used for road edge effect delineation in Nyungwe

2. Material and Methods

This chapter describes the methodological process followed by this study as summarized in the following flowchart

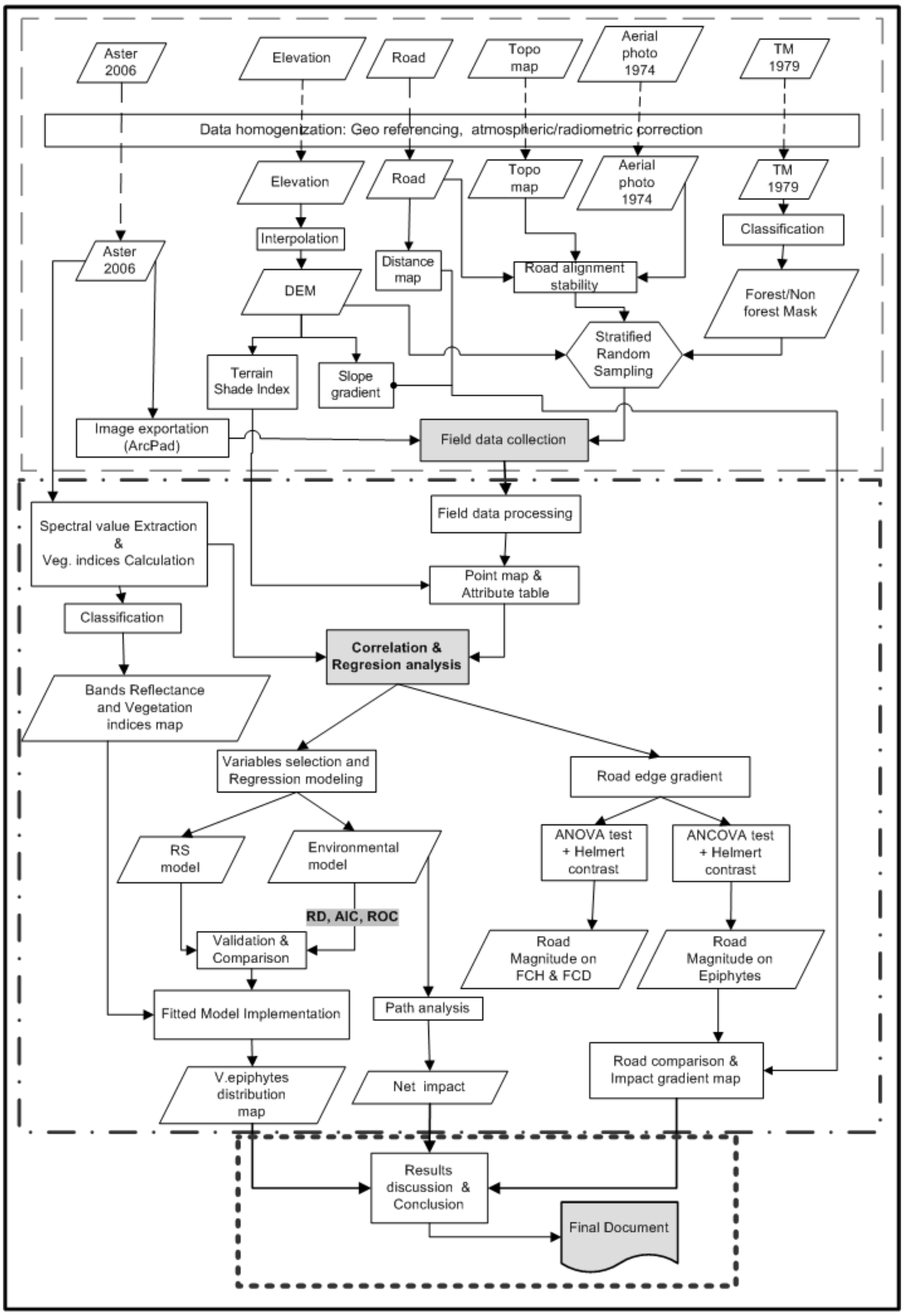


Figure 4: Methodological flowchart of road edge effect on forest canopy structure and epiphyte biodiversity

2.1. Study area: Nyungwe National Park

The Nyungwe National Park is a mountainous rainforest in south-western Rwanda between 2°15' – 2°55' S, 29°00'– 29°30' E (see figure 5A). Nyungwe is located in the Albertin rift; a series of mountain ranges beginning at the Rwenzori mountains in western Uganda and Congo, continuing south into the Lendu Plateau in Eastern Congo and contiguous with Kibira National Park in Burundi.

Temperatures at Nyungwe are generally cool with an average minimum temperature of 10.9° C and an average maximum temperature of 19.6 °C. The mean annual rainfall of 1,800 mm (Sun, Kaplin et al. 1996) is typical for an African rainforest. A major dry season occurs between July and August and a minor dry season takes place between December and January.

The conservation area is approximately 970 km^2 includes vast stretches of forest at elevation of 1,400 to 2,950 m asl. The forest is interrupted by two large swamps, Kamiranzovu (13 km^2, the largest peat bodies in Africa (Hamilton 1982)) and Uwasenkoko. Nyungwe shelters nearly 70% of the country’s waters feeding into two watersheds, the Congo and Nile Basins. Nyungwe’s forest protects the source of the river Nile, ensuring critical water supplies for downstream users in neighbouring countries and as far away as Egypt.

Because it is so large and located at these elevations, Nyungwe is one of the most biologically important mountain rainforest in Central Africa (Plumptre, Davenport et al. 2007). Nyungwe supports an abundance of plant and animal life. More than 260 species of trees and shrubs have been found in Nyungwe forest; including at least 24 that are believed to be endemic to the Albertin Rift (Dowsett 1990). Nyungwe forest is also one of the most important sites for bird conservation in Africa with a total of 260 bird species, 25 of which are endemic to the Albertin Rift (Plumptre, Masozera et al. 2002). Thirteen species of primates are known to inhabit the forest, including chimpanzees (*Pan troglodytes schweinfurthii*), owl-faced guenons (*Cercopithecus hamlyni*) and Angolan black and white colobus monkeys (*Colobus angolensis ruwenzorii*), the latter living in groups of more than 300 individuals.

Being located in one of the most heavily populated areas of Africa with over 8 million inhabitants in a country of 26 338 Km^2 size, Nyungwe forest is under constant threat from anthropogenic and environmental stresses. Nyungwe was first gazetted as a forest reserve in 1933. Yet, this status did not prevent people from utilizing the forest (alluvial mining of gold, honey collection, wood cutting, hunting of animals). In 1984, the Rwandan Ministry of Agriculture completed a management plan for Rwanda’s remaining natural forests (DGF 1984). For Nyungwe, the goal of this plan was to ensure the conservation of the forest by subdividing it into (1) forest fringe zones where some timber harvesting would be permitted (~10% of all forest), (2) natural reserve zones where minimal use would be allowed (~40% of all forest), and (3) protected forest management areas where resources could be used sustainably (~50% of all forest). From the same year, research activities in the forest were motivated by the presence of the New York Zoological Society (now the WCS) but war and 1994 genocide put a halt to most of conservation activities.

However, in 2004 Nyungwe forest received National Park status from GoR and that makes it the largest protected high- elevation rainforest in East Africa.

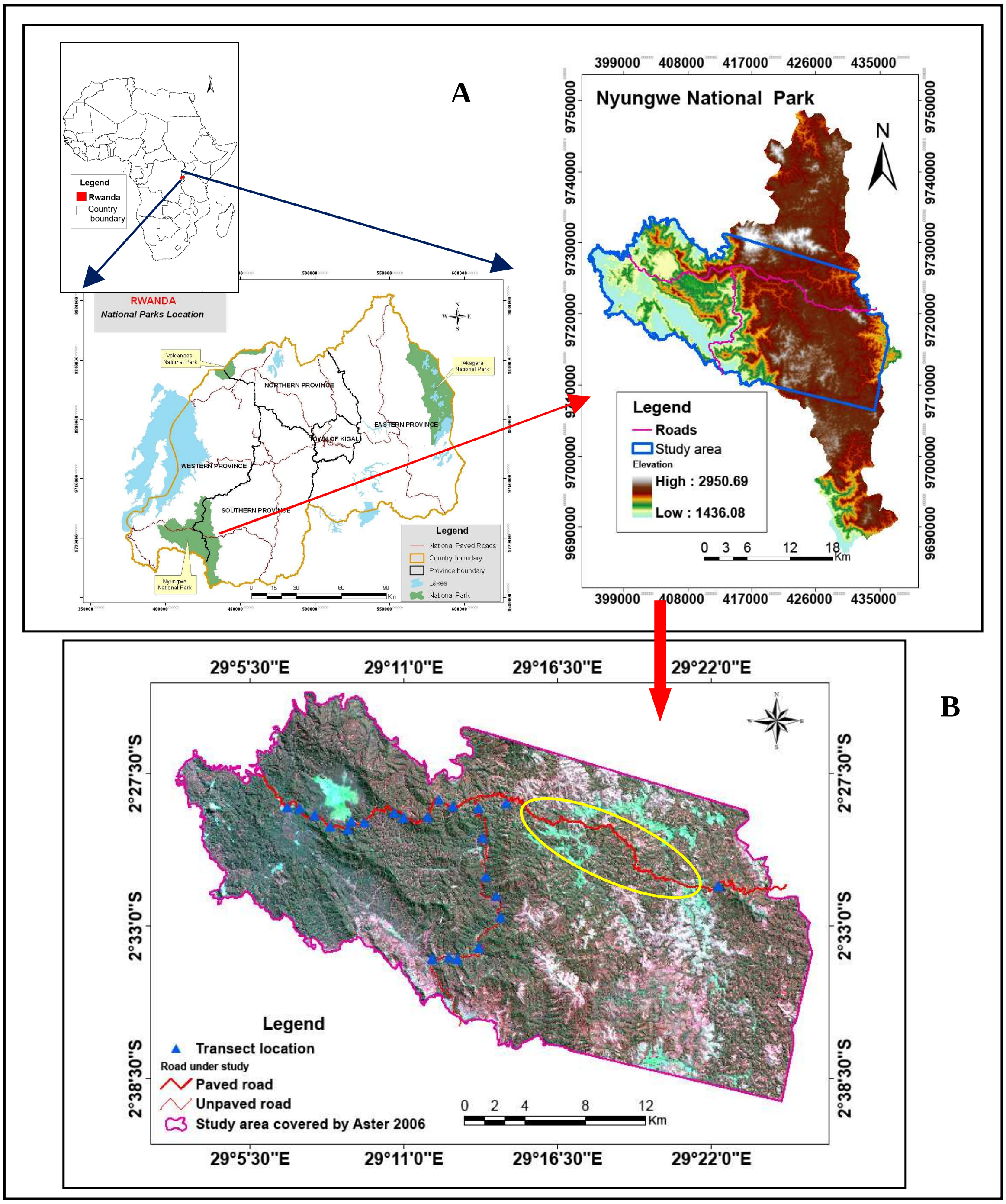


Figure 5:(A) Location of study area, (**B**) Aster image of July 2006, Bands321 composite covering study area with stratified sampling design for location of the transects.
The oval in yellow in figure 5B indicates the area highly disturbed by human activities: road alignment changes, large areas with signs of human activities like frequent burning.

2.2. Material and Preliminary data processing

Aerial photographs, edition 1974, satellites imagery (Landsat TM 1979, Spot-4 2000, Aster 2006), topographic maps of 1980 and other vectors data (road network, Elevation contours, park boundary) were obtained for the study area. These data were pre-processed in order to make them suitable for field work preparation to the further analysis. Images were geometrically corrected using Ground Control Points (GCPs) and projected to the local projection system: Universal Transverse Mercator (UTM) 35^{o}S zone with Clarke 1880 spheroid, Map Datum: Arc 1960, False Easting: 500000, False Northing: 10000000, Central Meridian: 30, Scale Factor: 0.9999, Latitude of Origin: 0.00. Two images of 16 July 2006 from Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) with each bands calibrated at radiance at sensor units (L1B) were available for our study area. 0nly the first 3 (VNIR) bands and 9 SWIR bands were used in the analysis. Resampling to 15 m from the original 30 meters spatial resolution of the SWIR bands was performed before stacking them with the 15 meters resolution VNIR bands into one single file. This was applied to the rest of the Aster level 1B images. Two Aster images were mosaiced into a single image, where after subset with the extent of the study area was created. Atmospheric and radiometric corrections were performed to eliminate possible perturbations for several vegetation indices calculated for further analysis. We used the latest ‘ATCOR Calibration for Aster algorithm’ (GEOSYSTEMS 2007). After preparation the image was imported into a desktop and Arcpad Mobile GIS platform to be used to the field surveys.

Table 2: Data type and information

Data type	Variable	Source
1. Literature review		
	Autecology of epiphyte Epiphyte species list	▪ General publication ▪ Scientific papers,…
2. RS and GIS data		
Topographic map 1988	General information, Contour lines 25 m equidistant used to create DEM.	MININFRA
Slope map and TSI	Generated from DEM	
Aerial photographs 1974 Landsat TM 1979	Sampling design (road alignment stability)	CGIS-NUR and Geodata Warehouse - ITC
Aster June 2006	Forest canopy density, height, epiphyte mapping	Geodata Warehouse - ITC
Administrative boundary	Sampling design	CGIS-NUR
Road network	Study area delimitation	MININFRA
Human traces in forest	Sampling design	PCFN
3. Field observations		
Burned area	Sampling design	Field work
Canopy height Vascular epiphyte	Attributes tables and Points maps	Transect survey
Canopy cover density Radiation intensity	Attributes tables and Points maps	Analysis of hemispherical photos
Elevations, Aspect and Slope	Attributes tables and Points maps	Transect survey

An unsupervised classification was performed using Aster images to create a forest/ non-forest (mainly savannas and swamp) image map. Forested area was the first condition for sampling design. The whole computation processes used various software environments as summarized in the table 3 below.

Table 3: Software used

	Software	Usages
1	ERDAS IMAGINE 9.1	Image processing
2	ILWIS 3.3	Image processing, calculation
3	ArcGIS 9.2	Mapping
4	ENVI 4.3	Spectral value extraction
5	Gap Light Analyzer version 2.0	Canopy cover density and Light intensity calculation
6	SPSS 15.0	Statistical Modeling
7	Microsoft Office Excel 2003	Spreadsheet graph
8	Microsoft Office Word 2003	Reporting /writing
9	Microsoft Office Visio 2003	Reporting :Flowchart
10	EndNote v.9	Referencing
11	R 5.2.1	Geostatistic software for random sampling and data analysis

2.3. Transect selection

Transect/line methods have been used (Belinchon, Martinez et al. 2007). Using road length under gstat software, random distance of starting points for transect along road was placed: 20 starting points on paved road and 15 on secondary road. In order to minimise the influence of landscape factors on local conditions, we restricted the sampling to sites with:

(a) Limited variation in physical conditions: altitudinal range of 1600 – 2400 m forest, hillsides, aspects, slopes not abrupt.

(b) Forested area: areas naturally not covered by forest (savannas and swamp) were not sampled

(c) Lack of signs of human disturbance such as burned area, logging, mining activities and other human traces. Referring to the point map of human traces (Plumptre, Masozera et al. 2002), 2 km from forest edge has been considered for the first transect position. A big area has been kept out of sampling in the eastern part of the park due to serious forest fires of years of 1997 and 2006.

(d) Road alignment stability: Both selected roads have been created during the same period. Long time effect can be evaluated where road alignment does not change overtime. During pavement (in the 1980’s) the main road alignment deviated over long distance. Such road segment was not sampled. Aerial photography of 1974, Landsat TM 1975 and topographic map of 1988 interpretation completed by field survey have been used for excluding those areas.

(e) Overlap with other infrastructure or linear features such as tourist trail, rivers, and camping zones were avoided.

With these restrictions, only 14 transects were selected along the paved road and 9 transects along secondary roads (see figure 5B). Transects were laid out at a right angle from the road edge (clearing edge) to 100 m into the forest interior. A distance of 100m is also the optimal distance of gradient as documented by many previous studies in this field (Enserink 1997; Esseen 2006; Tanner and Perry 2006; Belinchon, Martinez et al. 2007; Delgado, Arroyo et al. 2007).

After two days of pilot field work exercise, we decided to place seven sampling points along each transect at the following distance from the edge in meters: 5m-15m-25m- 40m- 60m- 80m- 100m. The starting point of the transect corresponds to the *clearing edge* (because trees, population unit of our target population - forest- are absent within that area).

2.4. Field data collection

Quantitative and qualitative variables were collected on field during period of 13th September – 10th October 2007. The three main purposes of fieldwork were (1) measuring of tree canopy cover density (2) tree canopy height (3) counting of vascular epiphyte species and estimation of their cover (4) Other physical and vegetation description of visited points. The following information has been collected for all samples points (n= 161).

True-colour fisheye photographs technique has been chosen for canopy cover estimation (Fiala, Garman et al. 2006). Hemispherical canopy photography is one indirect optical technique that has been widely used in studies of canopy structure and forest light transmission (Dignan and Bren 2003; Montes, Rubio et al. 2007; Schleppi, Conedera et al. 2007). Hemispherical photographs has been taken for each sample points with fisheye lens attached to a Canon camera provided with a bubble level and fixed to a tripod at 1.2 m above the ground.

Canopy height is a fundamental variable for vertical distribution of epiphyte in tree branches. For the measurement of canopy height Haga height meter was used (FAO 2004). Standing at distance of 20 or 30 meters from trees, (distance equivalent to the tree height) shooting the trees crown base and top, two scale measures were recorded. Trees crown height is the difference of the crown base and crown top values. Accuracy of visual estimation was cross checked by multiple measurements using this instrument before applying it in some cases where to stand at a certain distance from tree and see the upper of crown was very difficult (area without trees canopy gaps).

Transect was also accessed vertically within each of seven samples points in a 100m horizontal transect. All trees species of more than 5 m high within a roughly defined plot of 3 m radius were considered for sampling epiphyte (Padmawathe, Qureshi et al. 2004). Besides presence/absence records, epiphyte species presence abundance was inventoried. Sampling epiphyte species was done through three to four means:

(1) Collecting fallen old branches, very often due to the age of host tree and wind. (2) Wood poles were used to get specimen of epiphyte till an approximated height of 15 meters. (3) Binoculars for well developed epiphyte in high canopies and (4) Climbing exercises were also used for observations and/or specimen collection in mid and top branches of tall trees.

Figure 6: Epiphyte specimen collection in the field

Specimen of unknown epiphyte species was collected in a white plastic bag and given a code or nickname. They identification was completed referring to the existing publications on Rwandan and Eastern Africa flora biodiversity. (Troupin 1978; Troupin 1985; Sir Michael Blundell 1987; Troupin 1988).

Epiphytic abundance or cover in host tree canopy was estimated visually. The visual estimation of the percentage of epiphyte cover on the bark surfaces was standardized during first two pilot days of our field survey. The value (for each epiphyte species cover) was a mean of 5 estimations done at 5 different zones of host trees as given by Lowman in 1995 (Lowman; and Wittman 1996): lower trunk, upper stem, based branch, mid branch and top branch. The cover percentages, as for any floristic composition analysis and ordination, were then converted to Braun–Blanquet’s cover classes (Mueller-Dombois and Ellenberg 1974) from 0.5 to 5 as follows: 0.5 (<1% cover), 1(1-5% cover), 2 (6 – 25 % cover), 3(26-50% cover), 4 (51-75% cover) and 5 (76-100% cover).

In the same sample points, the following additional information was recorded in field data collection sheet (appendix 1): X, Y coordinates and elevation using a GPS Garmin 12 receiver, slope gradient and slope aspect using clinometers and compass. Cover and height of each rainforest layer/stratum were estimated visually and by using a Haga height meter for height.

2.5. Data processing

2.5.1. Terrain parameters

Topographic attributes derived from Digital Elevation Model (DEM) have successful used as explanatory variables for the prediction of plant species distribution in mountainous areas (Lassueur, Joost et al. 2006; Zhao, Nan et al. 2006). For modelling vascular epiphyte, we used elevation, slope and terrain shade index.

a) Digital Elevation Model:

DEM was generated from the Elevation contour lines using ILWIS scripts (Hengl, Gruber et al. 2004). The contour lines of 25m equidistance shape file created by digitalizing from scanned, geo-referenced and geo-coded topographic map sheets at scale 1:50,000 of 1988 were available. Contours were rasterized using a common grid (15x15m) and the DEM from the contour data was created. Prior to the slope gradient map and terrain shape index calculation, the quality of DEM was improved by taking into account the features that are not shown by the contours such as ridges and valley bottom. The sinks were also filled. All these steps are well explained in terrain analysis user guide by Hengl et al.,2004 (Hengl, Gruber et al. 2003).

b) Slope gradient

Slope gradient map was necessary for distance weighting in road edge impact delineation. The slope map was created by using the digital elevation model, the height differences in X and Y directions were calculated and Slope map was generated using the following equation:

$$\boxed{\text{Slope gradient (\%)} = 100.\ \text{Sqrt}\ ((dx^2 + dy^2)\ /\ \textit{pixel size})}$$

[Equation 1]

Where dx: height difference of the pixel in x direction and dy: height difference of the pixel in y direction

Produced map was exported into ArcGIS for further analysis (see map in appendix 2).

c) Terrain shape index map (TSI)

Geomorphology becomes a key component of ecosystem classification systems because it is a dominant factor influencing vegetation distribution and landforms are relatively stable landscape features. Quantified landform characteristics have been proved to be correlated with forest ecosystem description (Abella 2003). As defined by McNab (1989), terrain shape index represents the mean relative difference in elevation between the central pixel and its 8 neighbours. TSI is a combination of all information of surface shape of the site in one continuous variable: slope azimuth, slope gradient, position on the slope, length of slope and geometric shape of the site. TSI is a powerful ecological predictor. Henry McNab, proposed the following equation using a window of 5 x 5 pixels (McNab 1989):

$$\boxed{\text{TSI} = \text{dem} - \text{focalmean (dem, circle, 5)}}$$

[Equation 2]

The above equation has been implemented in ArcGIS/Spatial analyst tool and raster calculation for generating the terrain shape index map (see appendix3). From generated TSI map pixel based values have been extracted using spatial analyst tool- zonal statistics in ArcGIS and used as variable in further statistical model analysis.

2.5.2. Spectral value extraction and vegetation indices

Among available literature in vascular epiphyte studies, there is no one stating on their prediction using satellite imagery. The spectral variability information and derived vegetation indices were proved to be useful for vegetation characteristic estimation (Gilabert, Garcia-

Haro et al. 2000; Zhu, Yao et al. 2008). However, succeeded prediction based on some satellite information are not necessary useful in other area, because they perform differently in different vegetation background conditions (Joshi, De Leeuw et al. 2006). As such, the ideal vegetation indices for modeling vascular epiphyte are not known. Assuming that vascular epiphyte presence or absence will affect the canopy properties such as greenness or density, vegetation indices could provide a surrogate and quantitative measure of their presence and abundance in the canopy. The reflectance values at the locations of 161 samples points were extracted from each of 9 Bands of Aster images. We used ENVI 4.3 (Environment for Visualization of Image) software package, which can extract many spectral bands at the same time (Adam O'Connor 2007). Nine of commonly used vegetation indices were calculated and the corresponding image maps were produced with ArcGIS 9.2 (2006): Advanced Vegetation Index - AVI (Zhang, Pavlic et al. 2004); Difference Vegetation index. DVI (Tucker 1979); Normalized Differenced Vegetation Index. NDVI (Rouse 1974); Perpendicular Vegetation Index PVI (Richardson 1977), Ratio Vegetation Index RVI (Jordan 1969); Modified RVI - RSR (Brown, Chen et al. 2000), Soil Adjusted Vegetation Index – SAVI (Huete 1988) Modified SAVI- SAVI2 (Major, Baret et al. 1990) and Transformed SAVI – TSAVI (Baret and Major 1989). Spectral band spectral value and vegetation indices were first correlated to the vascular epiphyte distribution from road edge for testing if we can directly discriminate the spatial pattern from road edge to the forest interior. Correlation was also done with best predictor environmental variables of vascular epiphyte distribution (our initial expectation). Then, from spatial expression of the best linear regression equation we should map indirectly the spatial pattern of vascular epiphyte impacted by road edge.

Table 4: Reflectance based vegetation indices

Veget. index	Equation
AVI	B43 = B4 – B3 after normalization of the data range *f* (AVI) = B43≤ 0, AVI = 0; **Or** B43> 0, AVI = ((B4+1)*(100-B3)*B43)^1/3)
DVI	*NIR – Red*
NDVI	*(NIR – Red) / (NIR + Red)*
PVI	*(NIR – a Red –b)/ sqrt (1+a ^2)*a and b are intercept and slope values : a= 3.69, b= 1.17
RVI	*NIR / Red*
RSR	_RVI*[1- ((SWIR- SWIR min) / (SWIR max – SWIR min))]_ SWIR correspond to Band 4 in Aster and min and max are the observed reflectance values from the same Bands in the field points
SAVI2	*NIR / (Red +a/b*); **a** and **b** have the same values as in PVI
SAVI	_(1+L) *[(NIR – Red)/ (NIR+Red+L)];_ L= 0.5
TSAVI	*[a(NIR- aRed –b)] / [Red +aNIR- ab]* **;** **a** and **b** values are the same as in PVI

2.5.3. Hemispherical photographs analysis

The circular photographs taken skyward from the forest floor with a 180^o hemispherical lens were then analyzed using specialized image analysis software (Jonckheere, Nackaerts et al. 2005). Gap Light Analyzer (GLA), imaging software, were used to extract canopy structure and gap light transmission indices from true- color fisheye photographs (see picture in Appendix 4). Film was processed and dry negative were scanned in ITC Photo lab and converted into digital hemispherical JPEG images. Five principal steps to analyse a fisheye photograph (Gordon W. Frazer 1999) were followed: The first step was to open a jpeg image. Second, register the image so that both the orientation and circular extent of the exposure are known. The local magnetic declination for each sample point location was determined using online help (Geolab 2007). Thirdly, edit the configuration setting: image registration and distortion, site position and orientation, growth season and atmospheric conditions. Fourth, threshold the image in orders to classifier accurately each pixel as either a sky (white) or non-sky (black). Last, running the calculations to compute the canopy structure and transmitted gap light results. Canopy cover percentage was calculated by using canopy openness percentage result. Total light transmitted (in mJ $m^{-2}day^{-1}$) result were also selected to be used as one among environmental variables for prediction of vascular epiphyte (Sterck and Bongers 2001).

2.6. Data analysis and modelling

An exploratory data analysis has been done for investigating data distribution. Thus, data normality test was followed by Spearman’s rank correlation to measures the linear relationship between two variables. In this study, a correlation test was applied to find the correlation between forest canopy structure and epiphyte biodiversity with road, with a number of environmental factors and satellite information. Prior to statistical model development, most variables were $\log_{10}(x+1)$ transformed to meet the assumption of normality.

2.6.1. Road edge effects delineation

ANOVA and ANCOVA tests were completed to estimate the depth of the canopy structure and canopy vascular epiphyte biodiversity gradients.

Analysis of variance (ANOVA) with Helmert contrast have proven to be useful for delineation of road edge effects (Fraver 1994; Delgado, Arroyo et al. 2007). The helmert contrast for a given variable across all transects, compares the mean value at the edge with the mean value at each successive distance from the edge. The critical p-level for multiple comparisons was corrected by using the Bonferroni post hoc multiple comparisons (Kromrey and La Rocca 1995). A multiple comparison method such as Helmert is strongly recommended to avoid the chance of serial correlation in serial measures along road edge to interior transects (Bauer

1997). The edge reference level for contrast was fixed at 0 m of the road pavement edge. The results do not vary for purposes of the Helmert test if the opposite 100m to the forest interior is used. We also examined the effect of road type (secondary-narrow-road versus asphalt and relatively wide road) with ANOVA.

Analysis of covariance (ANCOVA) was used when analysing present species number and abundance of vascular epiphyte in relation to distance from the road edge. ANCOVA is a general linear model with one continuous explanatory variable and one or more factors. ANCOVA is a merger of ANOVA and regression for continuous variables. ANCOVA tests whether certain factors have an effect after removing the variance for which quantitative predictors (covariates) account (Sokal and Rohlf 1981; Schieck, Lertzman et al. 1995; Boyero, Rincón et al. 2006). The inclusion of covariates can increase statistical power because it accounts for some of the variability (Field 2008). Analysis of covariance was used for analysing abundance in relation to distance and presence as categorical variables. Forest canopy vascular epiphyte (presence and abundance) was tested by using: (1) summarised data of all families, (2) selecting one family and (3) one species of vascular epiphyte. Here, we have chosen the most common vascular epiphyte family and species in Nyungwe rainforest and occurring along both road categories.

2.6.2. Vascular epiphyte prediction

After collection and selection of predictor variables, two separate models were developed to predict vascular epiphyte biodiversity in Nyungwe rainforest: a field data related model using environmental variables and remote sensing related model, using spectral value from different bands of Aster images and reflectance based vegetation indices.

2.6.2.1. Predictors screening

Predictors choice is a major concern for building any predictive model (Hessami, Gachon et al. 2007; Lang, Nilson et al. 2007). Prior to training of the model, the variables were screened. The data set was small to be subsetted in training and test data set. Thus, the screening was done based on all data set (N = 161 = 98+63 respectively from paved road and secondary road). The following statistical techniques was applied (Sokal and Rohlf 1981): (1) test of collinearity: in par wise scatter plots and Spearman’s rank correlation coefficient. We adopted Spearman’s rank correlation because, after exploratory data analysis, we found that our variables data was not normally distributed; (2) separation test between variables and vascular epiphyte presence absence using box plots and (3) statistical significance test using Pearson’s Chi-squared test after visualizing cross classification tables.

2.6.2.2. Modeling technique

We used the GLM (General linear models) statistical model, to address our data with weak linear relationships. The GLM model and GAM (Generalized Additive models) have been proved to be useful in ecological modeling with any form of data: abnormal distributed data, continuous and/or categorical independents (Nelder and Wedderburn 1972; Pampel 2000). In this study, GLM- stepwise logistic regression can fit well our data for prediction of vascular epiphyte biodiversity, on the basis of continuous and/or categorical independent variables. Different model fitting parameters (e.g.: likelihood ratio test) allows us to choose between backward and forward stepwise logistic regression model output. Forward selection is the usual option, starting with the constant-only model and adding variables one at a time until some cut-off level is reached (the step at which all variables which are not in the model have significance higher than 0.05). Backward selection starts with all variables and deletes one at a time, in the order they are least significant by some criterion. There should be also a reasonable number of independents variables because "the more independents , the more likelihood of multi-collinearity" and the risk to find one variable to be significant just by chance is very high (Pampel 2000).

Logistic regression does not assume a linear relationship between the dependents and the independents. It may handle non-linear effects even when exponential and polynomial terms are not explicitly added as additional independents because the logit link function on the left-hand side of the logistic regression equation is non-linear (McKelvey and Zavoina 1994). Logistic regression applies maximum likelihood estimation after transforming the dependent into a logit variable (the natural log of the odds of the dependent occurring or not). The model is expressed as:

$$\boxed{\theta = \frac{e^{(\alpha + \beta 1\, x1 + \beta 2\, x2 + \ldots \beta i\, xi)}}{1 + e^{(\alpha + \beta 1\, x1 + \beta 2\, x2 + \ldots \beta i\, xi)}}} \qquad \textbf{[Equation 3]}$$

Where θ is the probability (p); α is the regression coefficient for the intercept, x_i are set of predictor variables and the β_i values are the regression coefficients (for variables 1 through n) computed from the data.

2.6.3. Model validation and comparison

The results of the logistic regression can be assessed by looking at the classification (Table 5), showing correct and incorrect classifications of the dichotomous, ordinal, or polytomous dependent. In our case, with binary data of vascular epiphyte distribution, we further used the most important significance tests: residual deviance information and the area under the ROC (Receiver Operating Characteristics) curve were calculated.

a) Residual deviance information:

For binary data such as vascular epiphyte distribution fitted with logistic regression, the residual deviance is used. Residual deviance is calculated as twice the negative of the difference between the log-likelihood deviance of the model with p parameters and the null model. This follows an asymptotic chi-squared distribution (Nagelkerke 1991). Thus, a significant model has a residual deviance greater than the chi critical value at a certain confidence with n degrees of freedom ($X^2_{0.05,\ 1\ d.f}$) as expressed in the following equation.

$$-2*[LL\ (N) - LL\ (0)];\ \text{Where } LL = \sum Y.\ln(p) + (1-Y).\ln(1-p) \qquad \textbf{[Equation 4]}$$

When the reduced model is the baseline model with the constant only, the likelihood ratio test tests the significance of the researcher's model as a whole.

A well-fitting model is significant at the 0.05 level or better, meaning the researcher's model is significantly different from the one with the constant only (Trexler and Travis 1993).

b) Receiver Operating Characteristic (ROC) curves

The Operating Characteristic (ROC) curve is a widely used statistical technique for assessing accuracy of predictive models (Pepe 2000).The ROC plot is obtained by plotting the fraction of correct classified cases on the y axis (sensitivity: proportion of the true positive) against the fraction of the wrong classified cases (specificity: proportion of false positive) on the x axis. The area under the ROC curve (AUC) provides a threshold independent measure of overall model accuracy (Gellrich, Baur et al. 2007). The values of the ROC vary from 0.5 indicating low similarity between observed and predicted value to 1.0 high similarity. The area under ROC curve was graded based on: AUC = 0.5 is “no discrimination” between observed and predicted value, 0.7< AUC< 0.8 “acceptable discrimination”, 0.8 <AUC< 0.9 “is excellent” and AUC > 0.9 is “outstanding”.

By using SPSS 15.0 software, a ROC curve was computed considering probability value extracted from saved prediction model output as test variables and field data of vascular epiphyte presence/absence as state variable. ROC curve graph and area under the curve (AUC) table with standard error, asymptotic significance and asymptotic 95% confidence level results were compared in order to choose the best predicting model.

c) Akaike’s information criterion (AIC):

The AIC shows great promise for various applications in ecology, conservation biology, behavioral ecology and physiology. Its strength is particularly in model selection, for situations generated by observational studies conducted in the field, where regressions are sought to model a given pattern or process as a function of a number of independent variables (Mazerolle 2008).

In case of model comparisons, the Akaike’s information criterion (AIC) was calculated. The models with small values of AIC are the ones that better fit the data. This index is typical used for comparing two models with different number of factors (but generated from the same data set) and chose which is the best between them. Akaike, 1973 (cited by Peide Shi (Shi; and Tsai 1998)) developed that information criterion which he defined as:

$$\boxed{AIC= -2(\text{log-likelihood}) + 2K}$$

[Equation 5]

Where K is the number of estimated parameters included in the model (i.e., number of variables + the intercept). The log-likelihood of the model given the data, is readily available in statistical SPSS output.

The statistics analyses were performed in SPSS 15.0 (SPSS, 2006) using tables created in Excel software. Columns are from field data compilation and/or with others variables generated using GIS and RS software (ENVI 4.3, Ilwis, ArcGIS).

Table 5: Model discrimination for Presence/absence pattern

Observed		Predicted		
		Vascule epiphyte absence/presence		Percentage correct
		0	1	
Step	0	a	b	F1
	1	c	d	F2
	Overall percentage			total

O: Absence, 1: Presence

The sensitivity is given by d / (d+c) and the specificity is a / (a+b).

The positive predictive value : d / (b+d) and negative predictive value : a / a+c

2.6.4. Path analysis

Environmental data are highly interrelated and some are often left out of the model. Hence, a path analysis was conducted to determine the direct and indirect role of distance from road as a single environmental factor in predicting vascular epiphyte. Path analysis is a powerful statistical tool that was developed to help observational data interpretation (Sokal and Rohlf 1995). An independent variable can indirectly change a dependent variable as a result of its influence on additional independent variables (Eubanks 2001). One can follow a chain of causality from the independent, causal variable, through the intermediate independent variable, to the response variable. Path coefficients quantify the strength of each direct effect on the response variable. A path coefficient is a standardized partial regression coefficient and is a statistical estimate of the change expected in the response variable for a given change in the causal variable (Sokal and Rohlf 1995).

When the path goes from a background variable through one or more intermediate variables and then on the response variable, the net effect of that background variable on the response (vascular epiphyte distribution in our case) is estimated as a compound path coefficient. A compound path coefficient is the product of all coefficients along a pathway. If more than one pathway connects background and response variables then the compound path coefficient are summed to estimate the entire effect coefficient (Sokal and Rohlf 1995; Iriondo, Albert et al. 2003).

2.6.5. Spatial visualization

Two different final maps have been created from statistical analysis output: a buffer-based map using distance from the roadside and a vascular epiphyte presence probability level map.

Based on the statistically defined road edge gradient, distance related maps of increasing species presence/abundance, forest canopy cover and height within different distances from roads (buffer based map (UNEP 2002)) was produced using road and slope maps as intermediate output: Roads of study area extracted from national road network dataset and classified referring to the five classes defined by Ministry of Infrastructures (MININFRA): national paved road, national unpaved road, district road, secondary road and minor road or trail.

The distance raster map from roads under study (paved road and secondary road) was created and cost weighted using the slope map in ArcGIS 9.2, spatial analyst tools. We adopted a classification of the produced raster map according to the impact gradient and road category.

While creating the prediction map, generated model equations were applied to selected predictor variables. The probability map of vascular epiphyte presence is a product of “Raster calculation” in ArcGIS using mathematical operation (plus or minus). The predictor variable maps multiplied its coefficient. For visualization, created maps of impact gradient and probability level were classified in three or four different classes.

Output maps were also crosschecked for accuracy, using field data points and value extracted from generated map. Extraction of pixel value of prediction maps was done using ArcGIS, spatial analyst/zonal statistics. Further, they were used for area under ROC curve calculation.

3. Results

3.1. Data characteristics

Seven sample points were placed horizontally and vertically on a 100 m perpendicular transect from road edge into forest interior. Forest structure data with emphasis on canopy cover density, canopy height and canopy vascular epiphyte biodiversity was collected. Statistical test of above variables reveals that 161 samples come from an abnormal distributed population of observations. All data are asymmetrical distributed and even after $\log_{10}(x+1)$ transformation the skewness persisted for some of them. Descriptive graphs in Appendix 5 serve as a visual examination of asymmetrical data distribution.

Exploratory examination of Pearson pair wise correlation matrix (see appendix 6) of above variables with environmental and remote sensing factors, revealed relatively poor relationship between forest canopy structure and vascular epiphyte biodiversity with spectral values and vegetation indices ($r = 0.37$ as the highest between forest canopy density and DVI) than environmental factor ($r = 0.64$, relation between vascular epiphyte abundance and forest canopy height).

3.2. Road edge effect gradient

3.2.1. Gap and forest structure along road

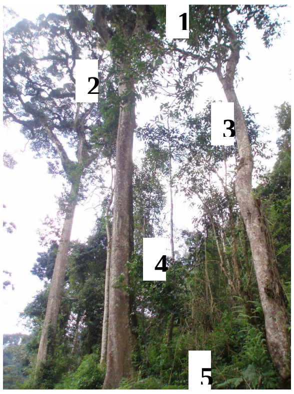
Forest gaps in Nyungwe created by roads are large in paved road with an average of 13 meters width for pavement and cleared area, while the secondary road has 3 to 5 meters width (see pictures in Appendix 7). From roadside to the forest interior grasses cover, shrubs, short trees like *Hagenia abyssinica*, leave the place to the trees and emergent. Some exotic trees species (like eucalyptus, Pinus) are also observable at roadside.

Five different forest layers (table 6) are observable in Nyungwe rainforest according to the altitudinal distribution of vegetation and degree of degradation.

Elevations sampled points of our field survey were comprised between 1698 and 2535 m asl. Closed forest with very high percentage cover of very large and tall emergent and trees was found in low elevation and less disturbed zone like southern part of study area (1600 – 1900 m asl with mean cover ≥ 80%). Open forest was commonly found at high elevation (mean of cover ≤ 70 % around 2300 m) or in the area highly disturbed. The herbaceous layer, dominated by one species of fern (*Pteridium aquilinum*) was most often found near the road or in the area with human disturbance signs like illegally logged or burned zones.

Table 6: Nyungwe rainforest stratum description summary

Layer	Names	Description
1	Emergent	Very tall trees (> 30 m) beyond optimal canopy level
2	Trees (Canopy)	Trees of regular canopy 15 – 30 m
3	Understory	Small trees (by size or age) from 4 to 15 meters
4	Shrub	1 to 3 m height vegetation
5	Forest floor	Basal surface (Bare), Stones, Litter and grasses (vegetation of less than 1 m of height)



The photograph was taken in Bweyeye region in September 2007 during field work and is showing five different forest structure layers.

There is a relatively poor cover of emergent and tall trees near the paved road. Wind and mass movement destroy them. Areas not covered by vegetation (rare in Nyungwe rainforest) with bare soil or stones and very little grass are found within 25 m from paved road due to erosion resulting from water collected by the road. Vegetation cover type are highly disturbed by traffic derived wastes and pollutants. Road run-off water conveys the traffic derived pollutant into drainage network at different distances along the road according to their weight, land steepness and rainstorm erosion fluctuations.

Figure 7: Traffic related wastes and erosion gullies on steeper hillside cleared by road construction and maintenance.

Roadside along paved road kept different pollutants like car's engine oil, plastics and others non biodegradable solids wastes which destroy vegetation cover along road. After road construction, certain sterilized zone (bare soil and rocks exposed) became terrain of erosion and landslide movement scenarios instead of being recovered by vegetation.

However, there is also altitudinal gradient of vegetation cover. During our fieldwork, we observed distinct zones of vegetation characterized by changes in height and species of the dominant trees, the growth forms of certain plants, and in the density and type of the understory. The inferior zone covers largely the southern part of the study area in the region crossed by unpaved road. The sub alpine zone was not presented in our study area.

Table 7: Altitudinal variation of vegetation in Nyungwe rainforest

Horizon	**Vegetation type**
Inferior zone (1400 -1600m)	Very tall and larges trees of 35 to 40 m. we can list: *Parinari excelsa*, *Newtonia buchananii*, *Symphonia globulifera*, *Entandrophragma excelsum*, *Albizia gummifera* and *Carapa grandiflora*.
Medium zone (1600-2250)	Normal height trees with 20-35m. The following trees species occur: *Entandrophragma excelsum*, *Parinari excelsa*, *Prunus Africana*, *Ocotea usambarensis*, *Chrysophyllum gorungosanum*
Superior zone (2250 -2500m)	Small trees with 15 to 20 m heights. The most occurring trees species are: *Podocarpus milanjianus*. Mosses and lichens are often presents
Subalpine zone (> 2500m)	Trees are very rare, short shrubs species like *Philippia benguellensis* and grasses cover the area.

Table 7 summarizes the description of Nyungwe vegetation based on Storz (1983) description.

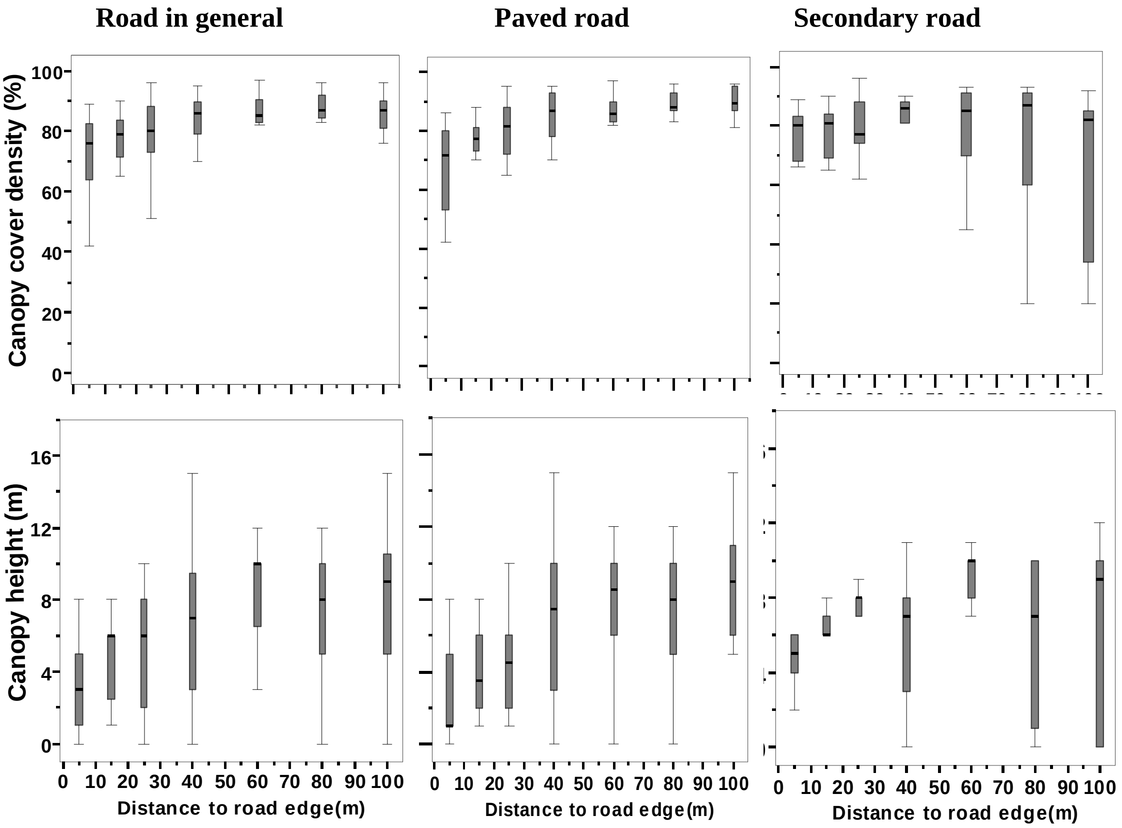


Figure 8: Variation in canopy cover and height with distance from the road in general, paved road and secondary road to the interior of the rainforest. Mean values are shown in the box plot.

Table 8: Road edge effects on forest canopy structure (ANOVA test) and forest canopy vascular epiphyte biodiversity (ANCOVA test).

Variable	Distance to road	Canopy		Epiphyte (Presence & Abundance)		
		Density (%)	Height (m)	In general	One family	One Species
Road in general	SS	3906.9	435.2	485.8	65.6	32.4
	df	6	6	7	7	7
	MS	651.2	72.5	69.4	9.4	4.6
	F	1.6	**6.3**	**27.3**	**39.2**	**118.8**
	P	0.162	**0.000**	**0.000**	**0.000**	**0.000**
Paved road	SS	7281.1	472.8	358.3	46.6	19.9
	df	6	6	7	7	7
	MS	1213.5	78.8	51.2	6.6	2.8
	F	**3.1**	**7.4**	**22.1**	**23.7**	**64.8**
	P	**0.009**	**0.000**	**0.000**	**0.000**	**0.000**
Secondary road	SS	1159.9	90.4	3.5	22.0	12.6
	df	6	6	6	7	7
	MS	193.3	15.1	0.6	3.2	1.8
	F	0.5	1.2	0.9	**26.9**	**57.8**
	P	0.829	0.309	0.494	**0.004**	**0.000**

SS: Sum of Squares; df: degrees of freedom; (7 distances to road), MS: quadratic mean or root mean square; P: significance level, set at α= 0.05; significant F tests are shown in bold.

We have detected overall significant gradients for forest canopy cover and height (table 8 and figure 8). Using individual Helmert difference contrasts (table 9), forest canopy cover stabilised at 15 meters from road edges in general and at 25 meters from edge of paved road (p>0.05). Forest canopy cover did not differ significantly along the secondary road (p>0.05 for all distances). We have found a very large gradient for forest canopy height along roads in general and along the paved road canopy height stabilised at 40 m from road edge. Likewise, canopy height did not differ significantly along the secondary road. Thus, road type significantly affects gradient in canopy structure (Table 7) in Nyungwe rainforest (Canopy density: F= 3.1, p= 0.009 for paved road and F= 0.5, p= 0.829 for secondary road; Canopy thickness: F= 7.4, p=0.000 on paved road and F=1.2 p= 0.309 on secondary road).

Table 9: Helmert contrasts for the road edge effect on forest canopy structure and vascular epiphyte biodiversity

Variable	Distance to road	Canopy		Vascular epiphyte		
		Density (%)	Height (m)	In general Pr/abund	One family	One species
Road in general	5	**0.044**	**0.000**	**0.006 / 0.000**	**0.002**	0.340
	15	0.420	**0.002**	**0.003 / 0.014**	**0.015**	0.475
	25	0.846	0.130	0.065 / 0.052	0.182	0.475
	40	0.624	0.143	0.654 / 0.215	0.103	0.634
	60	0.818	0.795	0.405 / 0.288	0.182	1.000
	80	0.874	0.437	0.306 / 0.535	0.550	0.236
	100				.	.
Paved road	5	**0.001**	**0.000**	**0.001 / 0.000**	**0.000**	**0.010**
	15	**0.002**	**0.000**	**0.001 / 0.005**	**0.011**	0.770
	25	0.432	**0.001**	0.064 / **0.009**	**0.024**	0.845
	40	0.813	0.085	0.106 / 0.079	0.088	0.559
	60	0.432	0.386	0.169 / 0.079	0.088	0.121
	80	0.649	0.386	0.224 / 0.439	0.129	0.436
	100				.	.
Secondary road	5	0.363	0.232	0.917 / 0.146	**0.043**	**0.036**
	15	0.162	0.841	0.676 / 0.769	0.475	0.790
	25	0.207	0.789	0.530 / 0.146	0.475	0.790
	40	0.285	0.789	0.177 / 0.769	0.634	1.000
	60	0.187	0.164	0.676 / 0.558	1.000	0.288
	80	0.420	0.841	0.917 / 1.000	0.236	0.594
	100				.	.

Distance to the road beyond which no significant variation was detected is shown as a change from a significant value (bold) to a non significant value of p (significance level set at α= 0.05) for a given variable. Vascular epiphyte in general has species number and abundance information separateley.

Direct road edge impacts on forest structure and biodiversity are very important along paved road in Nyungwe rainforest. Considering 15 m of gap created by road (pavement and cleared area) with disturbance width of 50 m (25 m on both roadside of impact gradient), the overall forest degradation concern 65 meters width.

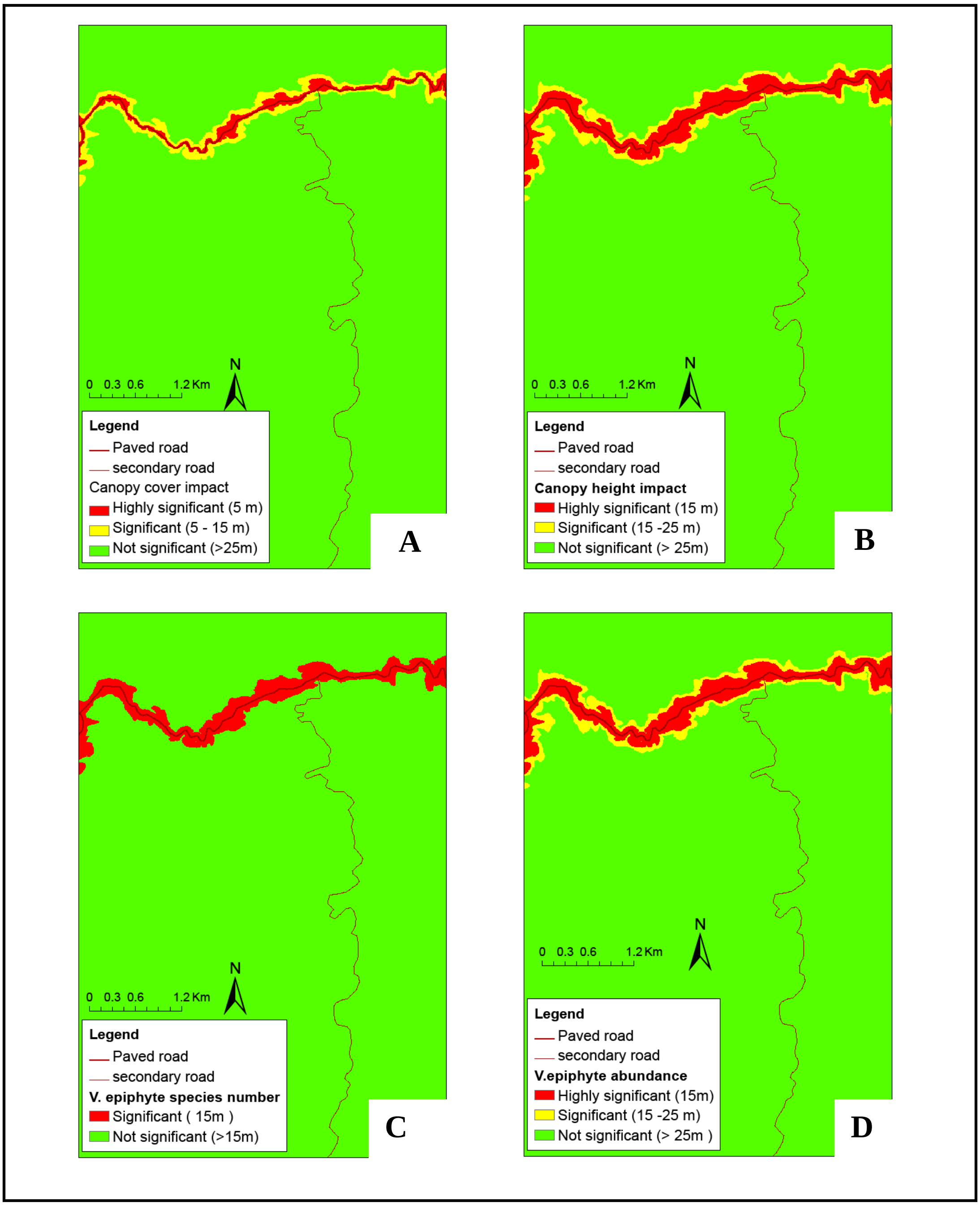


Figure 9: Road edge impact gradient on (A) forest canopy density; (B) forest canopy height/thickness; (C) number of forest canopy vascular epiphyte species and (d) abundance of forest canopy vascular epiphyte.

There are three different classes: (1) High significant impact zone ($p \leq 0.001$): in a distance where impact is significant by combining data of both road categories, (2) Significant impact zone($p \leq 0.05$): distance interval within which road edge impact is only significant along paved road and (3) non significant impact zone: from distance over which road edge impact is no more significant ($p > 0.05$).

3.2.2. Vascular epiphyte biodiversity

3.2.2.1. Vascular epiphyte composition in study area

In all 161 sampled points for canopy vascular epiphyte biodiversity, 70 species grouped in 15 families have been found (Table 10). A total of 50 species of vascular epiphyte belonging to 14 families were recorded around paved road. There was one more family “Begoniaceae” (15 in total) and 7 species more (57 in total) in the vicinity of the secondary road. The difference seems to be marginal in general, but we can notice that there was fewer orchidaceae species along the paved road (14 species) than in the secondary road area (28 species).

Table 10: Vascular epiphyte inventoried during transect work (September- October 2007)

Nº	Family	Number of species		Nº	Family	Number of species	
		Paved road	**secondary road**			**Paved road**	**secondary road**
1	Aspleniaceae	8	5	9	Oleandraceae	1	1
2	Orchidaceae	14	28	10	Lomariopsidaceae	1	0
3	Polypodiaceae	5	8	11	Dennstaedtiaceae	3	1
4	Grammitidaceae	2	3	12	Hymenophyllaceae	3	1
5	Vittariaceae	4	2	13	Lycopodiaceae	1	0
6	Piperaceae	2	3	14	Dryopteridaceae	2	2
7	Woodsiaceae	2	1	15	Begoniaceae	0	1
8	Thelypteridaceae	2	1				

The same species was present in both road categories; plus the difference in number as additional species for specific road category. See Appendix 8 for details in species inventoried during field work. The most frequently occurring and abundant vascular epiphyte species belong to the family of Aspleniaceae (40 % of all samples points). Begoniaceae was the least frequent family (3% of all samples points) and found only in an area of secondary road. With all species recorded, Orchidaceae was the most species rich family (40% of the total).

3.2.2.2. Species presence and abundance gradient across the transect

When the relationship between presence and abundance of vascular epiphyte along different distances was examined (see ANCOVA test result in table 8 and figure 10**a**), road vicinity emerged to be significantly influencing variable (F= 27.3, p= 0.000). The influence persisted until 15 m from roadside for both species number and species abundance for road in general. The gradient is larger for species abundance in paved road where effects persisted until 25 m from road edge (table 8). Vascular epiphyte presence and abundance did not show significant difference between distances from secondary road edge. But when we consider an individual vascular epiphyte family and species, the significance hidden by overall means appeared (table 8 and figure 10**b**, **c**). The impact is significantly with 5 m from secondary road edge (see table 8). We used Aspleniaceae and *Asplenium sp.* as most occurring vascular epiphyte family and species respectively, in both road category regions. In both roads categories, proximity condition is affecting Aspleniaceae species distributions in general (F= 26.9, p= 0.004) and *Asplenium sp.* as individual species presence and abundance (F= 57.8, p= 0.004) in Nyungwe rainforest (table 7, figure 10 b**, c**).

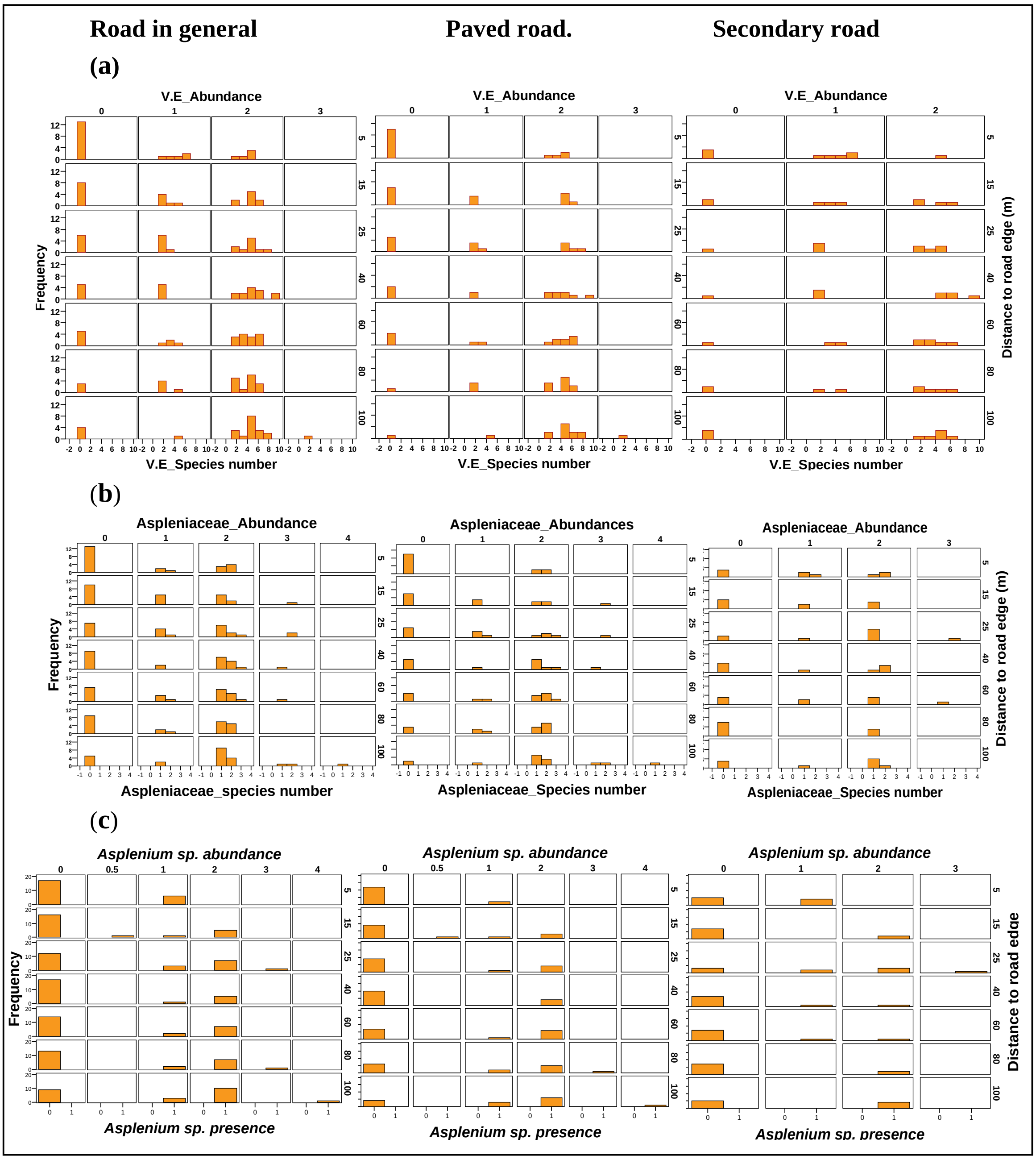


Figure 10: Relationship between proximity to the road and species number and abundance of vascular epiphyte expressed by Blaun Blanquet scale for (**A**) all data in general, (**B**) for one epiphyte family "asplenianceae" (**C**) and for one vascular epiphyte species "*Asplenium sp*."along both road categories.

Homogenized scale of frequency and distance to road are in vertical axis. Presence and abundance are in horizontal axis. Vascular epiphyte absence (species number and abundance = 0) are higher in road vicinity and decrease with distance from road to the forest interior.

3.3. Canopy vascular epiphyte distribution modeling

3.3.1. Model specification and explanatory variables selection

Vascular epiphyte (species number present and abundance) data were converted into presence-absence data. The assumption of binomial distribution allowed for the specification of the statistical model to be used.

Presence/absence data of vascular epiphyte was predicted using (1) environmental variables: eight variables related to forest canopy structure and five more variables characterizing the habitat and (2) by using remote sensing variables: vegetation indices and band reflectance.

In analysis phase we used the field data and spectral value of satellite image pixels corresponding to the field plots. Relationship test between collected predictor variables and response variable were assessed before running the model. Summarized table and graphs have been shown in Appendices 9 and 10. Canopy vascular epiphyte presence/absence was positively correlated to all variables determining the forest canopy structure plus distance to road and negatively correlated to light intensity, slope aspect, slope gradient, elevation and almost all vegetation indices and Aster image bands (see table 11).

Table 11: Correlation between independent variables and vascular epiphyte distribution

Environmental variables	**r**	**RS related variables (Aster images)**	**r**
Canopy covers density (FCD)	0.54**	Aster Band 1 (B1)	-0.26**
Canopy thickness or height (FCH)	0.61**	Aster Band 2 (B2)	-0.34**
Emergent height (Em_H)	0.41**	Aster Band 3 (B3)	-0.30**
Emergent cover (Em_C)	0.41**	Aster Band 4 (B4)	-0.13.
Trees height (Tr_H)	0.33**	Aster Band 5 (B5)	-0.23**
Trees cover (Tr_C)	0.27**	Aster Band 6 (B6)	-0.09
Understory height (Und_H)	0.32**	Aster Band 7 (B7)	-0.22**
Understory cover (Und_C)	0.19*	Aster Band 8 (B8)	-0.22**
Distance to road edge (Dist.)	0.26**	Aster Band 9(B9)	0.25*
Elevation (Alt.)	-0.34**	DVI	-0.26*
Slope gradient (Slope)	-0.11.	NDVI	-0.17.
Slope aspect (Aspect)	-0.09.	PVI	0.13.
Light intensity (L_int)	-0.54**	RVI	-0.17*
Terrain shade index (TSI)	-0.26**	RSR	0.05.
		SAVI	-0.17.
		SAVI2	-0.18.
		TSAVI	-0.30**

Non parametric correlation ranks accompanied by significance code: '**' Significant at the 0.01 level; '*' Significant at the 0.05 level. '.'Not significant correlation (> 0.05). These variables were passed over in statistical modeling.

3.3.2. Vascular epiphyte distribution prediction with environmental variables

We carried out a stepwise logistic regression of the vascular epiphyte presence/absence with canopy cover density, canopy thickness or height, emergent height, emergent cover, trees height, trees cover, understory height, understory cover, distance to road edge, elevation, light intensity and topographic position.

3.3.2.1. Logistic regression models

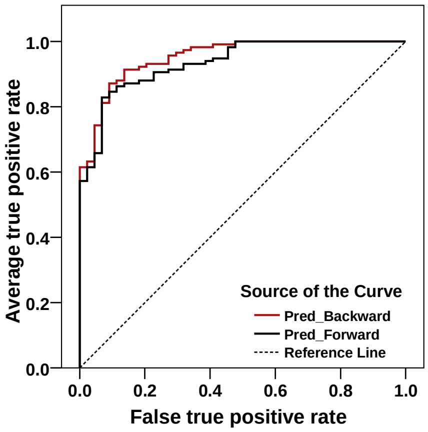
Forward and backward stepwise logistic regression was used after assessing relationships among variables variables. Both procedures for selection of the variables to include in the multiple logistic regressions have given best models for predicting the probability of vascular epiphyte distribution (Table 12).

Table 12: Summary of the logistic regression models for predicting the probability of vascular epiphyte distribution using environmental variables

Model 1: Backward stepwise elimination				**Model 2: Forward stepwise entry**			
Variable	Coeff.	Std Error	Pr (>/z/)	Variable	Coeff.	Std Error	Pr (>/z/)
Constant	0.206	2.656	0.104	Constant	1.544	2.439	0.527
Trees height	0.088	0.035	0.012	Canopy height	0.362	0.099	0.000
Emergent cover	0.077	0.025	0.002	Canopy density	0.070	0.023	0.002
Canopy density	0.087	0.024	0.000	Elevation	-0.004	0.001	0.001
Elevation	- 0.004	0.001	0.003				
TSI	- 0.707	0.239	0.003				
Distance to road	0.025	0.011	0.026				
Residual deviance: 72.2 **AIC: 86.2**				**Residual deviance: 92.5** **AIC: 100.5**			

Probability for stepwise: entry: 0.01, removal: 0.05

Backward stepwise elimination model predicted vascular epiphyte distribution with 5 explanatory variables namely Terrain shade index (-0.707), Tree height (0.088), Canopy density (0.087), Emergent cover (0.077), Distance to road (0.025) and Elevation (-0.004). Model 2, result from forward stepwise entry, used three explanatory variables: Canopy height (0.365), canopy density (0.070) and Elevation (-0.004). Comparison summary in table 11 and figure 11 shows that model 1 and Model 2 was slight different for some significance test parameter.



Test models	AUC	Std error	Asymptotic significance	Asymptotic 95% confidence interval	
				Lower	Upper
Model 1	0.953	0.016	0.000	0.921	0.984
Model 2	0.935	0.019	0.000	0.898	0.973

Figure 11: Comparison of ROC curves of two spatial model using environmental variables

Both models included few variables considering the total number of variables in Table 11. However, most of 14 variables enumerated in table 11 are strongly interrelated. Furthermore, the direct and indirect impact of road edge proximity should be assessed.

3.3.2.2. Net impact of distance to road on vascular epiphyte distribution

Direct and indirect impact of other variables on vascular epiphyte distribution has been also assessed using path analysis procedure. To fully assess the direct and indirect impact of all environmental variables collected on vascular epiphyte distribution needed a separate regression for each variable and thus 14 distinct analysis. To focus the analysis on our objective (road proximity impact), the path model presented in figure 12 summarizes the most direct and indirect significant impact of distance from road edge on the vascular epiphyte distribution. Eight variables have a strong direct/indirect relationship with vascular epiphyte distribution as shown in Figure 12.

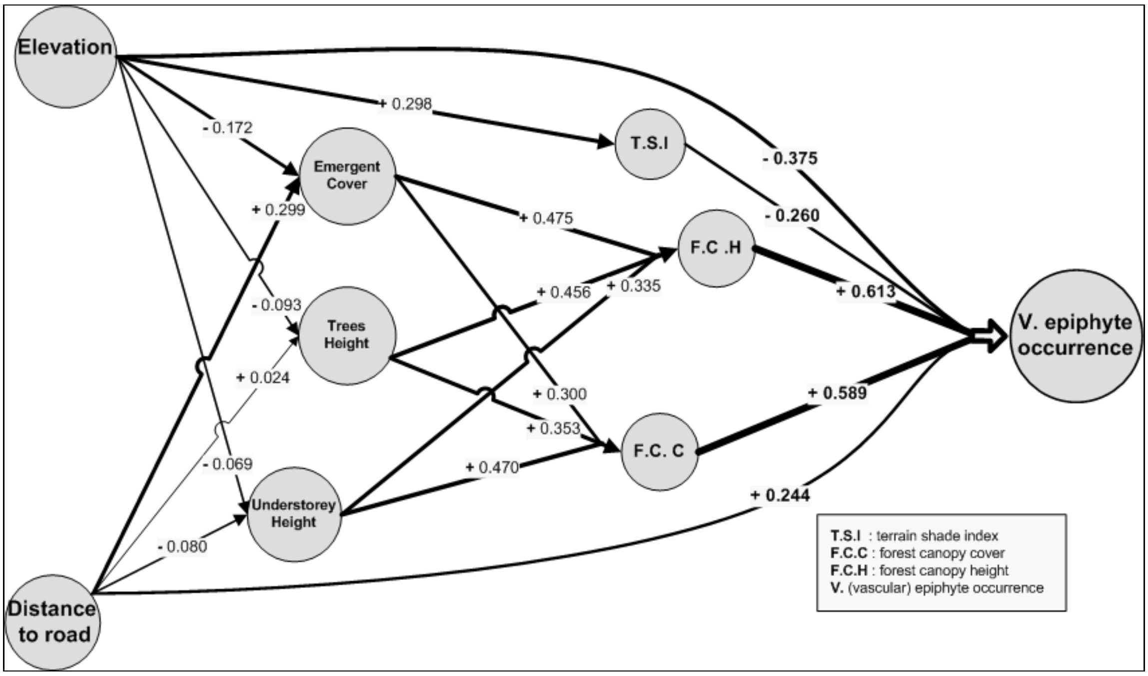


Figure 12: Path analysis model of direct and indirect effects of environmental variables on the vascular epiphyte distribution.

Single headed arrow indicates significant effects of environmental variables and path coefficients (in standardized coefficients) indicate positive or negative relationships. The line width is proportional to the size of path coefficients.

The Path analysis revealed that distance to road edge and elevation have an important direct influence on vascular epiphyte. Specifically, the analysis indicated that distance from road edge is one of the five important environmental control factors of vascular epiphyte distribution (+ 0.244). That is, a one standard deviation increase in the probability of vascular epiphyte to be present would result in a 0.244 standard deviation increase in the distance from road edge to the forest interior. Indirect impact of distance to road edge on vascular epiphyte is also very significant to the forest canopy cover and height through their main determinant forest strata in Nyungwe rainforest: Emergent cover percentage (+ 0.299); Trees height (+ 0.024); and Understory height (- 0.080). Unexpectedly, the analysis indicated a negative relationship of distance to road edge with understory height. The negative relationship with understory height is not surprising considering the advantage taken by understory species when emergent and big trees are disturbed. However, the overall impact of distance to road edge is strong (sum of product of 7 different path compound coefficient) is equal to + 0.357. Elevation affects also importantly vascular epiphyte distribution with a negative direct impact of 0.375 and a net impact coefficient of - 0.612.

3.3.3. Vascular epiphyte distribution prediction with variables from satellites images

Following the extraction of spectral value of each band at sample points locations and calculations of vegetation indices, various regression models were employed.

3.3.3.1. Mapping best predictors environmental variables

Canopy cover, height maps with elevation (DEM) can spatially model the gradient from road edge to the forest interior of vascular epiphyte. However, the canopy cover and height variation from road edge was poorly correlated to the spectral information from available satellite image. Unfortunately, the variation was very short to be discriminated by aster image as shown in linear regression output (table 13).

Table 13: Linear regression model for forest structure layers

Model	R	R^2	Adjusted R^2	Std error of the estimate
Canopy cover	0.557	0.310	0.250	17.135
Canopy height	0.475	0.226	0.158	3.257
Cover emergent	0.295	0.087	0.041	28.992
Tree height	0.242	0.059	0.043	9.800

We used spectral values and vegetation indices in forward stepwise linear regression to predict canopy density and canopy height. The best fitted model with these variables explained only 25 % of canopy cover and 16% of canopy height variation from road edge to the forest interior.

3.3.3.2. Logistic regression with epiphyte presence/absence data

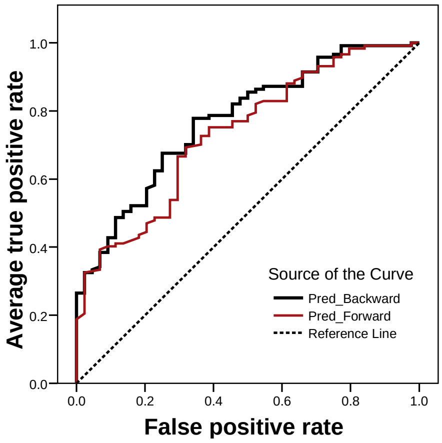
Logistic regression with vascular epiphyte presence/absence data and spectral value from each band and vegetation indices together give two different models (table 14) predicting vascular epiphyte occurrence.

Table 14: The summary of logistic regression models for predicting the probability of vascular epiphyte distribution using satellites images variables

Model 3: Backward stepwise elimination				**Model 4: Forward stepwise entry**			
Variable	Coeff.	Std Error	Pr (>/z/)	Variable	Coeff.	Std Error	Pr (>/z/)
Constant	11.922	3.300	0.000	Constant	8.327	1.767	0.000
Band 1	0.229	0.138	0.097	Band 2	-0.170	0.069	0.014
Band 2	-0.537	0.201	0.008	Band 3	-0.041	0.014	0.004
Band 6	0.229	0.142	0.106				
Band 9	-0.428	0.213	0.045				
SAVI2	-2.010	0.609	0.001				
Residual deviance: 155.5 (-2LL(0): 170.24)				**Residual deviance: 163** (-2LL(0): 170.24)			
AIC: 167.5				**AIC: 169**			

Probability for stepwise: entry: 0.05, removal: 0.10

Comparison summary in table 14 and figure 13 shows that model 3 was the best predictor of vascular epiphyte spatial distribution probability with acceptable area under curve of ROC and the lowest residual deviance and AIC value (RD: 155.5**,** ROC: 0.772, AIC: 167.5) Model 4 explains also a lot of vascular epiphyte spatial distribution probability with slight difference for some significance test parameter (RD: 163**,** ROC: 0.731, AIC: 169). However, model 4 uses fewer predictors (bands reflectance related variables) but explain 4.1% less than model 3. The area under ROC curve is graded as acceptable for discrimination between observed and predicted value (AUC 0.7< AUC< 0.8). The area under the ROC curve is less than the one given by using environmental predictors. However, it has an advantage for spatial prediction because all variables are easily mapped.



Test models	AUC	Std error	Asymptotic significance	Asymptotic 95% confidence interval	
				Lower	Upper
Model 3	0.772	0.039	0.000	0.695	0.849
Model 4	0.731	0.043	0.000	0.651	0.818

Figure 13: Comparison of ROC curves of two spatial models using RS variables.

Both models (model 3 and model 4) can be used for mapping spatial vascular epiphyte distribution probability in Nyungwe rainforest as shown by figure 14 generated using the equation 6 and 7:

$$\text{Log (p/p (1-p)} = 11.922+ 0.229*X_1+ 0.229*X_2 - 0.537*X_3- 0.428*X_4-2.010* X_5 \quad \textbf{[Equation 6]}$$

Where X_1 is Aster image band 1, $X_{2:}$ Aster image band 6, X_3: Aster image band 2, X_4: Aster image band 9 and X_5 is vegetation index SAVI2.

$$\text{Log (p/p (1-p)} = 8.322 - 0.170*X_1 - 0.041*X_2 \quad \textbf{[Equation 7]}$$

Where X_1 is Aster image band 2 and $X_{2:}$ Aster image band 3.

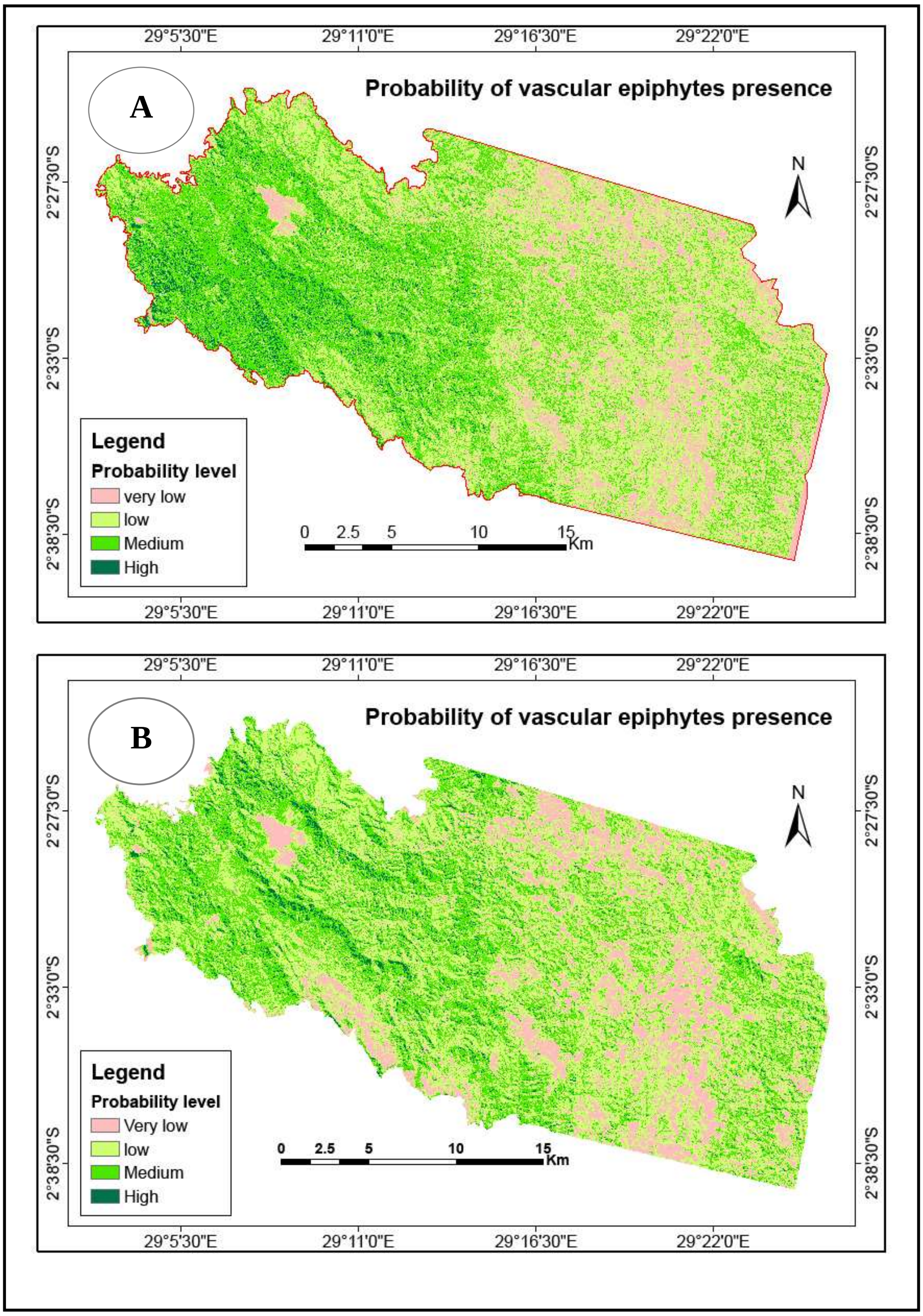


Figure 14: The predicted probabilities of occurrence for vascular epiphyte with (A) model 3 and (B) Model 4

The maps were classified in four classes: (1) Area where probability to find vascular epiphyte is very low: ≤ 0, (2) Medium impact: Area within which vascular epiphyte probability is low: 0 – 0.3 (3) Zone within which vascular epiphyte have more possibility to be present: 0.3 – 0.6 and (4) Area with high probability of vascular epiphyte to be present: ≥ 0.7. All open areas like swamps and savanna are well discriminated and given very low chance of having canopy vascular epiphyte. The largest area of the eastern part of the forest also has a lower probability than the western part. Even if road alignment is not well demarcated in the map, some important segments of paved road are clearly visualized when zooming in the map view.

The accuracy of produced maps was also crosschecked. The areas under ROC curve were calculated using the values extracted from prediction maps using Model 3 and model 4.

Table 15: Area under the curve from prediction maps

Variables (test result)	Area	Std error [a]	Asymptotic sig. [b]	Asymptotic 95% confidence interval	
				Lower Bound	Upper Bound
Model 3	0.757	0.039	0.000	0.681	0.832
Model 4	0.755	0.038	0.000	0.679	0.830

a: under non parametric assumption; b : Nul hypothesis: true area = 0.5

Comparing to the slight different in figure 13 above the results were similar. The mean value extracted from raster maps produced should be different to the mean value extracted fro intermediate output map.

4. Discussion

The result of the analysis of variance and covariance demonstrated that there is a very significant gradient of road edges on forest canopy structure and canopy vascular epiphyte biodiversity ($p \leq 0.05$). We modelled the vascular epiphyte occurrence by logistic regression. Two relationships were established, one with the environmental variables and the other with the aster image reflectance. The implications of the methods and results are discussed in this chapter.

4.1. Road edge effect and the road type

We detected that overall variation in canopy cover, canopy height and canopy vascular epiphyte biodiversity stabilised at 15m from the road edge. Changes persisted until 25 m to the interior of the forest for both canopy height and vascular epiphyte abundance along paved road. This is in line with the statement that 'Long-term impact of road edges tends to increase the forest disturbance created by the gap of road construction instead of regenerating and convalescing the gap' (Ali, Benjaminsen et al. 2005; Jonsson, Fraver et al. 2007). The secondary and paved roads, with road width of about 10 m were constructed around the 1930's through Nyungwe rainforest. Currently the direct impact extends beyond 15 m on both sides of the roads.

These results suggest that road edge effects defined by canopy cover and canopy height may be shorter for Nyungwe tropical mountainous rainforest than for other edge types, including some road networks studied on others continental ecosystems (Auerbach, Walker et al. 1997; Forman and Alexander 1998; Jaarsma and Willems 2002; Bignal, Ashmore et al. 2007). In Queensland forests (Australia), Laurance (1990) related the gradient to the forest status and reported that the most striking forest disturbance was evident up to 200 m inside fragmented forest margins. However, this result confirms findings from similar studies relating edge gradient to the forest fragment size and edge type such as in Amazonian rainforest fragments of Manaus-Brazil, where Mesquita et al. (1999) using ANCOVA test revealed that both the cover type of the surrounding area and distance to edge had significant effects on tree mortality within 0 –20 m. In laurel and pine forests (Tenerife, Canary Island) the canopy cover and height showed a general stabilising trend within the first 6-10 m of the road edge (Delgado, Arroyo et al. 2007).

The analysis of our data did not reveal a significant effect of the secondary road on the forest canopy structure and vascular epiphyte distribution (canopy cover: $F= 0.5$, $p = 0.829$; canopy height: $F= 1.2$, $p = 0.309$ and vascular epiphyte distribution: $F= 0.9$, $p = 0.494$).

As paved and secondary roads clearly differ in width, pavement material and in use (see appendix 7 and figure 7) our result of different intensity and reach of edge effects between road categories is not surprising. The variance and covariance analysis of the mean value did not discriminate rare disturbances on the canopy structure and vascular epiphyte distribution related to the road edge along the secondary road. Disturbance to the forest canopy structure and vascular epiphyte along the secondary roads was significantly less than the disturbance incurred along paved road. This result is in accordance with previous researchers that road width is a significant factor determining the road edge effect drift (Noss 1999; Jackson, Fredericksen et al. 2002). Figure 15 illustrates this finding. Different accelerations of wind in the gap created by road construction break a big tree along paved road, while small tree has losses only branches along a secondary road and keeps its orchids epiphyte mat hanging.

Figure 15: Tree broken and lost upper part along the paved road (picture a) and tree trunk without branches observed along secondary road (picture b).

Road construction and long-term maintenance as well as their use have influenced microhabitats conditions along the roadside. The detailed discrimination of patterns related to micro-conditions would need more field data to be split and analyzed in different groups. The disturbed forest structure, further used to justify the impact on biota characteristics, is a function of the different micro topography and substrate types (Abella 2003; Dignan and Bren 2003; Karim and Mallik 2008). In Nyungwe forest we can consider it in two different views. Firstly, geomorphologic aspects vary much over short distances and steeper slopes near the roadside are unstable. Secondly, there is an important variation of vegetation distribution related to that geomorphology and to the level of secondarization of the forest due to the human activities before implementation of conservation measures. Thus, variance analysis in distinct microhabitats should help to recognise the severity of the road effects. Such variation in vegetation patterns impacted by the road was found to be distinct in four different microhabitats namely shoulder, side slope, ditch and back slope from the edge of the road to the forest by Karim and Mallik (2008).

Edge orientation controls the penetration of directional influence like wind or sunlight and that could vary in different years, seasons or hours (Kumar and Skidmore 2000; Honnay, Verheyen et al. 2002; Lhotakova, Albrechtova et al. 2007). Thus, these justify the incorporation of terrain shade index in the prediction of vascular epiphyte distribution.

The extent of the forest canopy structure edges described here has high canopy and sub canopy damage and exceptional abundance of the herbaceous layer in the vicinity of the road (like *Pteridium aquilinum*), heavy lianas climbing trees "*Sericostachys scandens* and *Mimulopsis solmsii*". Furthermore, exotic species are introduced and are colonising the area along roads (e.g. Eucalyptus, Pinus). The impact on forest stand structure and composition by road edges have also been reported in other research findings (Cho and Boerner 1991; Kneeshaw and Bergeron 1998). Both invasive, native plants species and shade intolerant plant species take advantage of canopy disturbance (Babaasa, Eilu et al. 2004; Watterson and Jones 2006).

In this study, we aimed to determine the uneven distribution of arboreal plant species (vascular epiphytes) within micro environmental conditions created by road edge in a single rainforest ecosystem using ANCOVA test. The gradient is more significant for abundance than presence (table 9 of results). Existing trees near the road, especially along unpaved road did keep their epiphytes but with poor coverage (see the picture in figure 15b above). This means that, one vascular epiphyte species can easily be present at different distances from the road edge but with a different cover. Abundant vascular epiphyte communities were often found beyond 40 m from road edge. Trees with large and old branches covered by bryophytes mats accumulate a lot of humus and moisture and they host a dense vascular epiphyte community (figure 16 in front). This is in line with described requirements in terms of organic matter, light and moisture of vascular epiphytes (Hazen 1966; Gentry and Dodson 1987; Cascante-Marin, Wolf et al. 2006).

Figure 16: Old and undisturbed *Syzygium parvifolia* canopy with rich community of vascular epiphyte.

While around secondary road we observed seven more vascular epiphyte species than along paved road, there was a marginal difference in presence and abundance of vascular epiphyte families between paved and secondary road. Species belonging to Orchidaceae family are the most important (40% of species) and 70 % of them was present along secondary road. Moreover epiphytes are poorly inventoried as stated by Plumptre et al. (Plumptre, Davenport et al. 2007), Nyungwe is very rich in orchidaceae and more than 100 species have been listed by botanists to inhabitant Nyungwe rainforest (Fischer 1997; Plumptre, Masozera et al. 2002).

4.2. Independent variables best predicting vascular epiphyte distribution

4.2.1. Implication of canopy structure on vascular epiphyte distribution.

Relating plant species distribution patterns with environmental conditions is an important technique when the objective is to describe community structure with respect to a particular set of environment variables. In total, twelve predictor variables were screened to predict the probability of occurrence of vascular epiphyte. Eight variables out of 12 are related to the forest canopy structure: emergent height, emergent cover, tree height, tree cover, understory height, canopy cover density and canopy height. The result of the statistical screening (appendices 11 and 12) confirmed the assumption posed earlier in chapter one and the hypothesis 3 that: there is a significant interaction between distances to road edge-forest structure disturbance-vascular epiphytes presence /abundance.

From the boxplots and spearman’s correlation coefficient (-0.54), light intensity was among the predictors showing good separation between vascular epiphyte presence and absence records (see appendices 11 and 12). This is in accordance with other findings in radiation-vegetation relationships (Kumar and Skidmore 2000) and in particular light intensity and epiphyte biodiversity (Hietz 1997; Mucunguzi 2007). But, light intensity (total radiation transmitted) extracted from hemispherical photographs analysis, was not selected among the best predictors of vascular epiphyte distribution. Being a function of canopy density variation and terrain shade index, both highly weighted in all developed models, we should not be surprised by its poor weight (see appendix 12 B). Both models (logistic regression and path analysis) revealed that the probability of vascular epiphyte occurrence has a strong positive relationship with canopy cover, height and distance from road edge to the forest interior. A very strong negative relationship with elevation and terrain shade index was also revealed.

Canopy cover and **height** showed strong positive relationships with vascular epiphyte distribution. A positive influence of forest canopy cover and height on the occurrence of vascular epiphytes have been reported for flora and fauna life in tropical and mountain rainforests (Zimmerman and Olmsted 1992; Bedway 1996; Malizia 2003; Houle, Chapman et al. 2004; Laube and Zotz 2006). Canopy cover and height indicate the status of the rainforest ecosystem; their stability is the main factor for vascular epiphyte establishment, growth and abundance. A gradient in disturbance of canopy structure from the road edge is expressed by the presence/abundance of vascular epiphyte mats in Nyungwe rainforest (as illustrated in 4.1). This is in line with similar studies on epiphyte communities in tropical rainforests. A study in Bolivia showed that the epiphyte communities accumulate on a host tree according to its age and size; and the earliest time an epiphyte community is likely to reach its climax is approximately 25 years (Goddings, Greenwood et al. 2006). Most epiphytes utilize the light humus and heavy humus types of substrate. The correlation between nutrients and moisture in the substrates and the high diversity of epiphytes in the canopy crowns have been revealed in the Kibale National Park in Uganda (Mucunguzi 2007b).

Different studies correlating host trees identity (species e.g. physicochemical characteristics of the bark, tree architecture, or leaf phenology patterns) and the structuring of vascular epiphyte communities found very poor relations. But it has been proved that tree architecture; age in a specific zone has a specific and temporal impact on vascular epiphyte community (Laube and Zotz 2006). The forest structure in tropical rainforests as described in chapter one and three has five different layers. Shrub and forest floor layers are not considered as part of the canopy cover and height. But the remaining three are important for the definition of forest canopy thickness (height) and cover. They also play conjoint roles in the maintenance of suitable conditions for vascular epiphyte establishment: air moisture and humus retention: fallen leaves from the upper part of the canopy are kept in intermediate branches; mousses and other debris create the same conditions like in the ground.

Distance to road edge had also positive relationships with vascular epiphyte distribution. The abundance of vascular epiphytes increases with the distance from the road edge to the forest interior. Distance to road edge has been used as a single predictor in order to investigate the association between road network and vascular epiphyte distribution. Furthermore, the prediction needed to consider non road related variables too in logistic regression and path analysis. Distance to road is among the six best predictors of vascular epiphyte occurrence in Nyungwe rainforest. This finding is in accordance to the earlier studies which proved that the distribution of vascular epiphyte varies within the same sites according to proximity of disturbance factors (Kloster, Dix et al. 2004; Heylen, Hermy et al. 2005; Cascante-Marin, Wolf et al. 2006). The severity of road edge effect was uncovered by the net impact coefficient generated by path analysis. However path analysis did not cover the impact of the road edge on forest abiotic conditions. Temperature and air humidity should vary also with road proximity. Additionally that direct effect of the road edge to the air temperature and humidity related also to the road category and use was proved to have the same implications on the vegetation pattern around the road (Bogren and Gustavsson 1991; Chen, Franklin et al. 1993; Newmark 2001; Gombert, Asta et al. 2004). In other words, it can be said that vascular epiphyte distribution pattern is affected by roads in two different ways: disturbing its habitat niche (canopy structure) which indirectly affects also abiotic conditions. A direct impact also included the effect on the climatic micro–condition along the road with potential pollutant emission in the air and soil from road traffic.

Furthermore, there was a highly significant negative relationship between vascular epiphytes and **elevation** and **terrain shade index** which are inseparable. Nyungwe tropical and mountain rainforest landscapes consist of enumerable landforms of various sizes and shapes. Logistic regression analysis indicated that terrain shape index is a better predictor of vascular epiphyte distribution (table11 and appendix 12A). Terrain shade index variation is a function of altitude variation. That is why we stated that they play an inseparable /conjoint role in that particular case. The forest stand structure decelerates with increasing in altitude (as proxy for the altitudinal vegetation gradient). Nyungwe rainforest regroups different forest categories according to the topographic gradient and some authors have proposed four different horizons, as summarized in table 7 in the results.

Elevation is also a proxy for the altitudinal climate and soil gradient (Dai and Huang 2006). From foothills to high peak temperature and air humidity changes gradually. Both variables are important for vascular epiphytes. In highly undulating terrain like Nyungwe, landform varies a lot within small area. We have a mixture of different landform types: ridge tops, nose slopes, linear hill slopes, coves, stream ravines and stream bottoms.

The terrain shade index offer additional and important information for discriminating the implications of those changes on vegetation and climate, because elevation and exposition rather than soil types determine communities and site suitability in mountainous areas (Fontaine, Aerts et al. 2007). Thus, these variations explain the negative relationships between vascular epiphyte presence/abundance and terrain characteristics. Indications from limited publications available suggest that vascular epiphyte density and diversity increases as conditions get wetter. They appear to be more luxuriant in premontane, lower mountain and mountain rainforests, but especially in mid-mountain cloud forests (Williams-Linera and Lawton 1989; Hietz and Hietz-Seifert 1995). In Kibale National Park-Uganda, rainforest located in the same zone as Nyungwe (rift valley), Patrick Mucunguzi (2007) has recently found that beyond 2500 m vascular epiphyte became very rare.

4.2.2. Association of image reflectance related variables to the vascular epiphyte pattern along the road

We further related the distribution data of vascular epiphytes with satellite image information. The nalysis of satellite imagery provides a means to spatially appraise the dynamics of the structure and diversity of the forest (Carlson and Sanchez-Azofeifa 1999; Schlerf, Atzberger et al. 2005). The spectral reflectance of the Aster image was not sensitive to canopy structure variation from the road edge (with low R^2: 0.31 for canopy cover, 0.22 for canopy height, 0.06 for trees height and 0.09 for cover emergent). The sensitivity was relatively significant with binary data of vascular epiphytes (appendix 13). Using spectral values from each band and vegetation indices together and separately, forward stepwise regression always excluded all vegetation indices from the list of significant predicting variables. Vegetation indices alone do not improve the result from prediction by chance. Vegetation indices are calculated from band reflectance values which did not discriminate the small scale variations. Band 2 and band 3 of Aster image were useful to determine the presence and absence of vascular. This result was in accordance with the red and near infrared bands in discriminating the variation of vegetation reflectance. It is also an evidence of the important presence and cover of vascular epiphytes in Nyungwe rainforest.

Thus, there is a positive association between medium resolution image information and gradient in canopy vascular epiphyte distribution along the road as stated in Hypothesis 4: ‘There is positive association between medium resolution image information and gradient in canopy vascular epiphyte biodiversity along roads in Nyungwe tropical mountain rainforest’ However the positive association was not high due to the gradient width. With medium resolution image, reflectance value and vegetation indices discriminate a large scale variation (Meer, Bakker et al. 2001). Indices like NDVI are easily saturated in continuously forested areas and hence challenging their ability to discriminate that short variation.

4.3. Modelling the probability of vascular epiphyte distribution pattern along the road edge

4.3.1. The performance of logistic modelling algorithms

We applied the widely used logistic regression models in summarizing the relationships between species distribution and environmental variables (Nicholls 1989). Data characteristics (completeness and distribution) were a limitation to use a method which relates quantitative changes in vascular epiphyte species’ abundance with environmental variables (UCLA 2008).

The multiple logistic regressions with backward stepwise (Model 1) and forward stepwise (Model 2) gave good models for predicting probabilities of vascular epiphyte distribution in this study. Looking at the validation and comparison output values Model 1 was chosen as the best model (RD: 72.2, ROC: 0.953, AIC: 86.2). For model 2 the computation gave almost similar values (RD: 92.5, ROC: 0.935, AIC: 100.5). Comparing both models, the difference was not significant. The area under the ROC curve of model 1 is 0.953 2 while for model 2, the AUC value is 0.935. The AUC is translated as the probability that the model will correctly distinguish between two cases (DeLeo 1993). This means that with a probability of 95, 3% of Model 1 is able to correctly distinguish occurrence and non occurrence of vascular epiphytes for a given micro-environment, while model 2 explained 93, 5 %. However, model 2 used fewer environmental predictors while the explanation of vascular epiphyte distribution is slightly different compared to the first one (about 1.8% of difference). The area under ROC curve is graded as outstanding (AUC > 0.9) for both models.

Canopy height, canopy cover and elevation predicted the vascular epiphyte occurrence well in Model 2, while Model 1 has integrated three more variables (Terrain shade index, Tree height, Canopy density, Cover emergent, Distance to road and Elevation) to achieve almost at the same probability. Conventionally, a simple model which explains a lot about phenomena is said to be the best. Models using more variables are more at risk of fitting noise (Garson 2008).

All predictor variables affect the distribution of vascular epiphytes in Nyungwe rainforest but the predictors are also correlated among themselves. We should ask ourselves if all of these variables are affecting vascular epiphyte distribution directly, or might some of them act more significantly indirectly? Beyond our case (just fitting a model of vascular epiphyte distribution in Nyungwe rainforest), we needed to construct and evaluate an alternative structural model for assessing the impact of each variable (Sokal and Rohlf 1981).

4.3.2. Path analysis model for assessing the net impact of distance to the road edge

We introduced an analytical model known as path analysis. Sokal et al (1995) explain well how path analysis allows to quantify the strength of the net impact of each predictor. In this study, the path analysis could easily be created from the results of logistic models and literature review on vascular epiphyte autecology. The output of the path way compound was relatively straightforward and easy to understand. The analysis indicates that some variables were affecting the vascular epiphyte distribution indirectly. That was in accordance to other research findings, where path analysis was used to assess the net impact of particular predictors (Leduc, Drapeau et al. 1992; Eubanks 2001; Scobell and Schultz 2005; Marchand and Houle 2006). Moreover the assessed impact is important for understanding the processes in order to develop effective integrated management strategies especially if there is causality relationships or biological control impact (Padmawathe, Qureshi et al. 2004). Because, in biostatistical modelling it is not a matter of mathematical relationships between the variables (Sokal and Rohlf 1995).

From the path analysis diagram three groups of variables appears to control vascular epiphyte distribution: (1) **Forest canopy structure** (canopy cover and height): It is unlikely that tree height or any other variable of rainforest structure affects appreciably the vascular epiphytes distribution. The rainforest structure layers (emergent, tree and understory) directly affect canopy height and density and they indirectly act more significantly on vascular epiphyte niche suitability; (2) **Distance to road edge:** Roads are unlikely to affect vascular epiphyte distribution actively by their presence. An interaction with abiotic and biotic disturbances caused by roads explain its overall impact (a + 0.357 net impact, compare to the direct imact of + 0.224 as coefficient), (3) **Topographic characteristics** (Elevation and terrain shade index) increased their negative impact on vascular epiphyte distribution. Elevation shifted its coefficient from – 0.375 as direct impact to the – 0.612 as net impact. Terrain shade index keeps an important direct negative impact – 0.375 to the distribution of vascular epiphyte.

4.4. Mapping of distribution of vascular epiphyte impacted by road using satellite image information

Using our field data and aster image of 16 July 2006, the model explains up to 77% of the probabilty of vascular epiphytes to occur in Nyungwe rainforest. Considering the width of the road edge impact gradient, the resolution of Aster image and canopy biophysical characteristics, the accuracy of the maps is not surprising. The width of the road edge effect was very short, as expected before field work. Also, the variations were sometimes too small to be discriminated by a medium resolution image like Aster. The similarity in reflectance from different species (epiphyte, lianas, and trees phenology) cannot allow a small scale discrimination of presence and abundance of epiphyte related to road proximity. Available literature of application of remote sensing for detailed spatial description of forest structure and floristic diversity use high resolution imageries (Thenkabail, Hall et al. 2003; Bunting and Lucas 2006; Malenovský and R. Zurita-Milla b 2007; Malenovsky, Martin et al. 2008). The recent study used the concept of “ecological fingerprint” as a spatial description of forest structure and floristic diversity (Kalacska, Sanchez-Azofeifa et al. 2007).

5. Conclusions and Recommendations

All research questions and hypothesis were answered and verified. They are summarized in next paragraphs with conservation/management implications in Nyungwe rainforest.

5.1. Conclusions

The results of this study demonstrated that the road edge effects of roads on canopy cover, canopy height and distribution of canopy vascular epiphyte are very significant in the Nyungwe tropical and mountain rainforest.
We assessed that normal conditions of interior rainforests appear beyond 15 to 25 m from the road edge. The width of this road edge effect is highly related to the road category. Along paved roads this widths is ten meters more than along other roads. Such apparent widths of road edge effects may accumulate at the whole ecosystem scale and contribute to a significant reduction of net forest area and species richness.
The total amount of forest removed by roads in Nyungwe rainforest is 80 ha (0.8 km^2). A possible and direct consequence of this is the loss of habitat for wildlife. As Nyungwe rainforest is home of 13 different species of primates and most of them are very agile and they live in canopies, canopy gaps reduce their habitat area. Besides losing the habitat, life loss by road kills and change in animal behaviour due to frequent human contact is also important. Considering a disturbance width along the paved road of 65 meters (15 m of road gap + 25 m of impact gradient on both side) and a length of 50 km, an area of 3, 25 km^2 is disturbed (0.34% of the forest). The increase in marginal habitat for sun-loving animals/plants species and the introduction and colonization of exotic plants form additional cumulative impacts.

The relationships between vascular epiphyte presence/absence and environmental variables are non-linear and GLM provided effective ways in detecting these relationships. In total, 6 out of 12 selected variables accurately predict the probability of vascular epiphyte occurrence in Nyungwe rainforest. The variables include distance from the road edge, canopy cover and height as well as elevation and the terrain shade index. Ultimately, this study reveals strong relationships between vascular epiphyte occurrence and the terrain shade index, and a very poor weight of radiation in predicting vascular epiphytes.

This study indicates that path analysis could be very successful to predict causality and controlling relationships between environmental variables and vascular epiphyte presence in Nyungwe rainforest. The analysis has strengthened the effect of distance to the road edge on forest canopy structure and vascular epiphyte presence and abundance.

Furthermore, the model with satellite image information shows acceptable results in predicting spatial gradients of vascular epiphyte occurrence. There is a possibility to map spatial gradient of vascular epiphyte occurrence from road edge using high resolution spatial and temporal remote sensing and GIS data. With short distances and small variations in rainforest canopy structure and vascular epiphyte biodiversity, vegetation indices proved useless in predicting forest canopy cover, height and vascular epiphyte occurrence. Band 2 and band 3 of Aster imagery were useful in determining the presence and absence of vascular epiphytes.

5.2. Recommendations

Vascular epiphytes form an uncharted territory of research. It is recommended to assess their spatial and temporal distribution and abundance through:

- More sensitive statistical tests of variations in the gradients of forest canopy structure and vascular epiphyte biodiversity from the road edge to the forest interior;
- In additional to the delineation of gradients, develop a quantitative model of diversity and abundance;
- Using temporally and spatially high resolution rremote sensing and GIS data to define the algorithms that discriminate presence and abundance of vascular epiphytes in Nyungwe rainforest. The developed algorithms should be useful in monitoring spatial and temporal patterns of vascular epiphyte in Nyungwe forest.

This research offers an insight in the severity of impacts on abiotic and biotic phenomena by by roads, like the impact of road edges on wildlife, trees species distribution, air quality, soil and drainage network and pollution. This merits further detailed studies on biodiversity conservation in Nyungwe rainforest.

There is a much large chain of environmental change due to the road edges in Nyungwe rainforest than originally though, the findings of our study should aid in:

- The design of road schemes, integrating road management and construction in practices into forest conservation.
- In our case (Nyungwe national park), impact of road edges can motivate decision makers to develop adequate use and management of roads within the park.
- The assessed environmental impact may form part of scientific cost and benefit analysis supporting the need for developing alternatives for connecting Southern-west of Rwanda and DRC to the rest of the country without crossing Nyungwe rainforest.

6. References

Abella, S. R. (2003). "Quantifying ecosystem geomorphology of the Southern appalachian mountains." Physical Geography **24, 6, pp. 488-501.**

Adam O'Connor, M. (2007). "ENVI. Using ENVI with HiRISE Image Data." ITT Visual Information Solutions.

Alan R. Smith, K. M. P., Eric Schuettpelz, Petra Korall, Harald Schneider & and P. G. Wolf (2006). "TAXONOMY. A classification for extant ferns." Taxon 55(3): 705-731. .

Ali, J., T. A. Benjaminsen, et al. (2005). "The road to deforestation: An assessment of forest loss and its causes in Basho Valley, Northern Pakistan." Global Environmental Change Part A **15**(4): 370-380.

Arevalo, J. R. and J. M. Fernandez-Palacios (2000). "Seed bank analysis of tree species in two stands of the Tenerife laurel forest (Canary Islands)." Forest Ecology and Management **130**(1-3): 177-185.

Auerbach, N. A., M. D. Walker, et al. (1997). "Effects of roadside disturbance on substrate and vegetation properties in arctic tundra." Ecological Applications **Vol. 7, No. 1. (Feb., 1997), pp. 218-235.**

Babaasa, D., G. Eilu, et al. (2004). "Gap characteristics and regeneration in Bwindi Impenetrable National Park, Uganda." African Journal of Ecology **42,217 - 224**.

Baret, F. G., G. and D. J. Major (1989). "TSAVI: A Vegetation Index Which Minimizes Soil Brightness Effects On LAI And APAR Estimation." Geoscience and Remote Sensing Symposium, **I.t C.S o.R.S.I, 1355-1358**.

Bauer, P. (1997). "A Note on Multiple Testing Procedures in Dose Finding." Biometrics, **Vol. 53, No. 3. (Sep., 1997), pp. 1125-1128.**

Bedway, B. (1996). "Life above the branches: follow your nose to the rain-forest canopy and get a bird's-eye view of earth's most diverse ecosystem." From: Science World **1/12/1996**

Beebe, W. (1917). " Rainforest–The canopy …"another continent of life remains to be discovered"
Retrieved July 2007 from http://www.experiencefestival.com/a/Rainforest/id/1944965."

Belinchon, R., I. Martinez, et al. (2007). "Edge effects on epiphytic communities in a Mediterranean Quercus pyrenaica forest." Journal of Vegetation Science **18**(1): 81-90.

Bergl, R. A., J. F. Oates, et al. (2007). "Distribution and protected area coverage of endemic taxa in West Africa's Biafran forests and highlands." Biological Conservation **134**(2): 195-208.

Bignal, K. L., M. R. Ashmore, et al. (2007). "Ecological impacts of air pollution from road transport on local vegetation." Applied Geochemistry **22**(6): 1265-1271.

Bogren, J. and T. Gustavsson (1991). "Nocturnal air and road surface temperature variations in complex terrain " International Journal of climatology **1991, 11,443- 455**.

Boletta, P. E., A. C. Ravelo, et al. (2006). "Assessing deforestation in the Argentine Chaco." Forest Ecology and Management **228**(1-3): 108-114.

Boyero, L., P. Rincón, et al. (2006). "Case selection by a limnephilid caddisfly [Potamophylax latipennis (Curtis)] in response to different predators." Behavioral Ecology and Sociobiology **59**(3): 364-372.

Brown, L., M. J. Chen, et al. (2000). "A shortwave Infrared Modification to the Simple Ratio for LAI Retrieval in Boreal Forests: An Image and Model Analysis." Remote Sensing of Environment **71,16-25**.

Bunting, P. and R. Lucas (2006). "The delineation of tree crowns in Australian mixed species forests using hyperspectral Compact Airborne Spectrographic Imager (CASI) data." Remote Sensing of Environment **101**(2): 230-248.

Burgess, N. D., A. Balmford, et al. (2007). "Correlations among species distributions, human density and human infrastructure across the high biodiversity tropical mountains of Africa." Biological Conservation **134**(2): 164-177.

Butler, R. A. (2005). "A Place Out of Time: Tropical Rainforests and the Perils They Face . Retrieved Jan 2008 from http://rainforests.mongabay.com/."

Carlson, T. N. and G. A. Sanchez-Azofeifa (1999). "Satellite Remote Sensing of Land Use Changes in and around San Jose, Costa Rica." Remote Sensing of Environment **70**(3): 247-256.

Cascante-Marin, A., J. H. D. Wolf, et al. (2006). "Epiphytic bromeliad communities in secondary and mature forest in a tropical premontane area." Basic and Applied Ecology **7**(6): 520-532.

Castro-Esau, K. L., G. A. Sanchez-Azofeifa, et al. (2004). "Discrimination of lianas and trees with leaf-level hyperspectral data." Remote Sensing of Environment **90**(3): 353-372.

Chambers, J. Q., G. P. Asner, et al. (2007). "Regional ecosystem structure and function: ecological insights from remote sensing of tropical forests." Trends in Ecology & Evolution **In Press, Corrected Proof**.

Chen, J., J. F. Franklin, et al. (1993). "An empirical model for predicting diurnal air-temperature gradients from clearcut-forest edge into old-growth Douglas-fir forest. ." Ecological Modelling **Vol 67, 179-198**.

Cho, D. S. and R. E. J. Boerner (1991). "Canopy disturbance patterns and regeneration of Quercus species in two Ohio old-growth forests." Plant Ecology **93**(1): 9-18.

Cordeiro, N. J., N. D. Burgess, et al. (2007). "Conservation in areas of high population density in sub-Saharan Africa." Biological Conservation **134**(2): 155-163.

Dai, W. and Y. Huang (2006). "Relation of soil organic matter concentration to climate and altitude in zonal soils of China." CATENA **65**(1): 87-94.

DeLeo, J. M. (1993). ""Receiver Operating characteristic laboratory (ROCLAB): Software for developing decision strategies that account for uncertainty "Proceeding for the International symposium on uncertainty Modelling and Analysis. College Park, MD: IEEE." Computer society Press

Delgado, J. D., N. L. Arroyo, et al. (2007). "Edge effects of roads on temperature, light, canopy cover, and canopy height in laurel and pine forests (Tenerife, Canary Islands)." Landscape and Urban Planning **81**(4): 328-340.

DGF (1984). "Plan d'Action pour la Conservation et l'Amenagement des Forêts Naturelles de la Crête Zaire-Nil. Direction – Générale des Forêts. Ministère
de l'Agriculture, Kigali, Rwanda."

Didham, R. K. and J. H. Lawton (1999). "Edge Structure Determines the Magnitude of Changes in Microclimate and Vegetation Structure in Tropical Forest Fragments." Biotropica **Vol. 31 Issue 1 Page 17 March 1999**

Dignan, P. and L. Bren (2003). "Modelling light penetration edge effects for stream buffer design in mountain ash forest in southeastern Australia." Forest Ecology and Management **179**(1-3): 95-106.

Dowsett, R. J. (1990). "Enquete Faunistique et Floristique dans la Forêt de Nyungwe, Rwanda." Tauraco Research Report **No. 3.** : 140 pp.

Dykes, A. P. (2000). "Climatic Patterns in a Tropical Rainforest in Brunei." The Geographical Journal **166**(1): 63-80.

Eigenbrod, F., S. J. Hecnar, et al. (2008). "The relative effects of road traffic and forest cover on anuran populations." Biological Conservation **141**(1): 35-46.

Enserink, M. (1997). "Life on the Edge: Rainforest Margins May Spawn Species." Science of The Total Environment **Vol. 276, No. 5320.**: pp. 1791-1792.

Esseen, P. A. (2006). "Edge influence on the old-growth forest indicator lichen Alectoria sarmentosa in natural ecotones." Journal of Vegetation Science **17**(2): 185-+.

Eubanks, M. D. (2001). "Estimates of the Direct and Indirect Effects of Red Imported Fire Ants on Biological Control in Field Crops." Biological Control **21**(1): 35-43.

FAO (2001). " Food and Agriculture Organization of the United Nations (FAO), 2001.Global forest resources assessment 2000. Main report." FAO Forestry Paper **Rome, p. 140.**

FAO (2004). "National Forest Inventory. Field Manual Template." Forest Resources Assessment Programme **Working Paper 94/E Rome**: 84 pages.

FAO (2007). "World forest cover 2000. retrieved Sept 2007 from:http://rainforests.mongabay.com/0103.htm."

Fiala, A. C. S., S. L. Garman, et al. (2006). "Comparison of five canopy cover estimation techniques in the western Oregon Cascades." Forest Ecology and Management **Vol 217,107-146**.

Field, A. (2008). "5, C8057 (Research Methods II): Analysis of Covariance (ANCOVA) retrieved Jan 2008 from http://www.statisticshell.com/ancova.pdf."

Fischer, E. (1997). "Contributions to the Flora of Central Africa V: Two New Species of Impatiens (Balsaminaceae) from Eastern Zaire " Bulletin du Jardin botanique national de Belgique / Bulletin van de National Plantentuin van België **Vol. 66 No. 1/2**: pp. 63-71.

Fontaine, M., R. Aerts, et al. (2007). "Elevation and exposition rather than soil types determine communities and site suitability in Mediterranean mountain forests of southern Anatolia, Turkey." Forest Ecology and Management **247**(1-3): 18-25.

Forman, R. T. T. and L. E. Alexander (1998). "Roads and Their Major Ecological Effects." Annual Review of Ecology and Systematics **29**: 207-C2.

Fraver, S. (1994). "Vegetation responses along edge-to-interior gradients in the mixed hardwood forests of the Roanoke River Basin, North Carolina." Conserv.Biol. **8, 822-832.**

GAPUSI, R. J. (1999). "Identification et analyse des options stratégiques pour la conservation de la biodiversité de la forêt de Nyungwe." Kigali: 43 p.

Garson, D. G. (2008). " "Logistic Regression, from Statnotes: Topics in Multivariate Analysis." retrieved Jan.2008 from http://www2.chass.ncsu.edu/garson/PA765/logistic.htm."

Gatera, F. (2001). "Politique nationale de l'environnement au Rwanda." MINITERE, Kigali: 72 p.

Gell, P. A. and D. Mercer (1992). "Victoria's Rainforests: Perspectives on Definition, Classification and Management." Monash publications in geography **no. 41**.

Gellrich, M., P. Baur, et al. (2007). "Agricultural land abandonment and natural forest re-growth in the Swiss mountains: A spatially explicit economic analysis." Agriculture, Ecosystems & Environment **118**(1-4): 93-108.

Gentry, A. H. and C. H. Dodson (1987). "Diversity and Biogeography of Neotropical Vascular Epiphytes." Annals of the Missouri Botanical Garden **Vol. 74, No. 2** pp. 205-233.

Geolab (2007). "Local magnetic declination for any position on the globe retrieved Nov- Dec 2007 from http://www.geolab.nrcan.gc.ca/geomag/e_magdec.html ".

GEOSYSTEMS (2007). "ATCOR Calibration files for ASTER retrieved Sept ,2007 from http://www.geosystems.de/atcor/downloads/Calibration_Files_for_ASTER_in_ATCOR.pdf."

Gilabert, M. A., F. J. Garcia-Haro, et al. (2000). "A Mixture Modeling Approach to Estimate Vegetation Parameters for Heterogeneous Canopies in Remote Sensing." Remote Sensing of Environment **72**(3): 328-345.

Glenday, J. (2006). "Carbon storage and emissions offset potential in an East African tropical rainforest." Forest Ecology and Management **235**(1-3): 72-83.

Glenn, M. G., S. L. Webb, et al. (1998). "Forest integrity at anthropogenic edges: Air pollution disrupts bioindicators." Environmental Monitoring and Assessment **51**(1-2): 163-169.

Goddings, H., J. Greenwood, et al. (2006). "Vascular Epiphyte Diversity within the La Chonta Forestry Concession, Bolivia " Project Bosque, University of Edinburgh and the University of Uppsala.

Gombert, S., J. Asta, et al. (2004). "Assessment of lichen diversity by index of atmospheric purity (IAP), index of human impact (IHI) and other environmental factors in an urban area (Grenoble, southeast France)." Science of The Total Environment **324**(1-3): 183-199.

Gordon W. Frazer, C. D. C., Kenneth P. Lertzman (1999). "Gap Light Analyzer (GLA), Version 2.0: Imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs, users manual and program documentation." Simon Fraser University,

Burnaby, British Columbia, and the Institute of Ecosystem Studies, Millbrook, New York.

Green, R. H. (1980). "Multivariate Approaches in Ecology: The Assessment of Ecologic Similarity." Annual Review of Ecology and Systematics **Vol. 11. (1980)** pp. 1-14.

Hamilton, A. C. (1982). "Environmental History of East Africa: A study of the Quaternary." Academic Press, London.

Hansen, M. J. and A. P. Clevenger (2005). "The influence of disturbance and habitat on the presence of non-native plant species along transport corridors." Biological Conservation **125**(2): 249-259.

Hazen, W. E. (1966). "Analysis of Spatial Pattern in Epiphytes
" Ecology **Vol. 47, No. 4. (Jun., 1966), pp. 634-635.**

Hengl, T., M. Gruber, et al. (2003). Digital terrain analysis in ILWIS : lecture note. Enschede, ITC**:** 56.

Hengl, T., S. Gruber, et al. (2004). "Reduction of errors in digital terrain parameters used in soil - landscape modelling." International journal of applied earth observation and geoinformation : JAG **5**(2).

Hessami, M., P. Gachon, et al. (2007). "Automated regression-based statistical downscaling tool." Environmental Modelling & Software **In Press, Corrected Proof**.

Heylen, O., M. Hermy, et al. (2005). "Determinants of cryptogamic epiphyte diversity in a river valley (Flanders)." Biological Conservation **126**(3): 371-382.

Hietz, P. (1997). "Population dynamics of Epiphytes in a Mexican Humid Mountane Forest " The Journal of Ecology **Vol.85, No6(Dec.1997)pp 767-775**.

Hietz, P. and U. Hietz-Seifert (1995). "Composition and Ecology of Vascular Epiphyte Communities along an Altitudinal Gradient in Central Veracruz, Mexico " Journal of Vegetation Science **Vol. 6, No. 4 (Sep., 1995), pp. 487-498**.

Hill, J. L. and P. J. Curran (2001). "Species composition in fragmented forests: conservation implications of changing forest area." Applied Geography **21**(2): 157-174.

Hilson, G. (2002). "The environmental impact of small-scale gold mining in Ghana: identifying problems and possible solutions." The Geographical Journal **Vol. 168, No. 1, March 2002 pp.57-72**.

Honnay, O., K. Verheyen, et al. (2002). "Permeability of ancient forest edges for weedy plant species invasion." Forest Ecology and Management **161**(1-3): 109-122.

Houle, A., C. A. Chapman, et al. (2004). "Tree climbing strategies for primate ecological studies." International Journal of Primatology, **2004 (Vol. 25) (No. 1) 237-260**

Huete, A. R. (1988). "A soil-adjusted vegetation index (SAVI)." Remote Sensing of Environment **25**(3): 295-309.

Iriondo, J. M., M. J. Albert, et al. (2003). "Structural equation modelling: an alternative for assessing causal relationships in threatened plant populations." Biological Conservation **113**(3): 367-377.

Iskandar, H., L. K. Snook, et al. (2006). "A comparison of damage due to logging under different forms of resource access in East Kalimantan, Indonesia." Forest Ecology and Management **237**(1-3): 83-93.

Jaarsma, C. F. and G. P. A. Willems (2002). "Reducing habitat fragmentation by minor rural roads through traffic calming." Landscape and Urban Planning **58**(2-4): 125-135.

Jackson, S. M., T. S. Fredericksen, et al. (2002). "Area disturbed and residual stand damage following logging in a Bolivian tropical forest." Forest Ecology and Management **166**(1-3): 271-283.

Jay, R. M. (1998). " Model of Conductive Heat Flow in Forest Edges and Fragmented Landscapes." Climatic Change **Volume 39,1998,Page 487-502**

Jonckheere, I., K. Nackaerts, et al. (2005). "Assessment of automatic gap fraction estimation of forests from digital hemispherical photography." Agricultural and Forest Meteorology **132**(1-2): 96-114.

Jonsson, M. T., S. Fraver, et al. (2007). "Eighteen years of tree mortality and structural change in an experimentally fragmented Norway spruce forest." Forest Ecology and Management **242**(2-3): 306-313.

Jordan, C. F. (1969). "Derivation of Leaf **-** Area Index from Quality of Light on the Forest Floor, Ecology. ." The Ecological Society of America **50,4,663-666**.

Joshi, C., J. De Leeuw, et al. (2006). "Indirect remote sensing of a cryptic forest understorey invasive species." Forest Ecology and Management **225**(1-3): 245-256.

Kalacska, M., G. A. Sanchez-Azofeifa, et al. (2007). "Ecological fingerprinting of ecosystem succession: Estimating secondary tropical dry forest structure and diversity using imaging spectroscopy." Remote Sensing of Environment **108**(1): 82-96.

Karim, M. N. and A. U. Mallik (2008). "Roadside revegetation by native plants: I. Roadside microhabitats, floristic zonation and species traits." Ecological Engineering **In Press, Corrected Proof**.

Kent, M. and P. Coker (1992). Vegetation description and analysis : a practical approach. Boca Raton etc. ; London, CRC Press ; Belhaven Press.

Kloster, R. N., S. Dix, et al. (2004). "Epiphytes in Guatemala." (Field work report): p. 18

Kneeshaw, D. D. and Y. Bergeron (1998). "Canopy Gap Characteristics and Tree Replacement in the Southeastern Boreal Forest." Ecology, Vol. 79, No. 3. (Apr., 1998), pp. 783-794.

Koetz, B., G. Sun, et al. (2007). "Fusion of imaging spectrometer and LIDAR data over combined radiative transfer models for forest canopy characterization." Remote Sensing of Environment **106**(4): 449-459.

Kromrey, J. D. and M. A. La Rocca (1995). "Power and Type I error rates of new pairwise multiple comparison procedures under heterogeneous variances." Journal of Experimental Education **63, 343-362.**

Kumar, L. and A. K. Skidmore (2000). "Radiation-Vegetation Relationships in a Eucalyptus Forest." Photogrammetric Engeneering and Remote Sensing, **Vol 66, no2,Febr.2000, pp193-204**.

Lang, M., T. Nilson, et al. (2007). "The performance of foliage mass and crown radius models in forming the input of a forest reflectance model: A test on forest growth sample plots and Landsat 7 ETM+ images." Remote Sensing of Environment **110**(4): 445-457.

Lassueur, T., S. Joost, et al. (2006). "Very high resolution digital elevation models: Do they improve models of plant species distribution?" Ecological Modelling **198**(1-2): 139-153.

Laube, S. and G. Zotz (2006). "Neither Host-specific nor Random: Vascular Epiphytes on Three Tree Species in a Panamanian Lowland Forest." Annals of Botany **97: 1103–1114, 2006**.

Laurance, W. F. (1990). "Edge effects in tropical forest fragments: Application of a model for the design of nature reserves." Biological Conservation **57**(2): 205-219.

Laurance, W. F. (1991). "Edge effects in tropical forest fragments: Application of a model for the design of nature reserves." Biological Conservation **57**(2): 205-219.

Leduc, A., P. Drapeau, et al. (1992). "Study of Spatial Components of Forest Cover Using Partial Mantel Tests and Path Analysis " Journal of Vegetation Science **Vol. 3, No. 1 (Feb., 1992), pp. 69-78**.

Lhotakova, Z., J. Albrechtova, et al. (2007). "Does the azimuth orientation of Norway spruce (Picea abies/L./Karst.) branches within sunlit crown part influence the heterogeneity of biochemical, structural and spectral characteristics of needles?" Environmental and Experimental Botany **59**(3): 283-292.

Lindenmayer, D. B., J. F. Franklin, et al. (2006). "General management principles and a checklist of strategies to guide forest biodiversity conservation." Biological Conservation **131**(3): 433-445.

Lowman, M. D. and P. K. Wittman (1996). "Forest Canopies: Methods, Hypotheses, and Future Directions." Annual Review of Ecology and Systematics **27**: 55-81.

Lowman;, M. D. and P. K. Wittman (1996). "Forest Canopies: Methods, Hypotheses, and Future Directions." Annual Review of Ecology and Systematics, **Vol. 27. (1996), pp. 55-81.**

Major, D. J., F. Baret, et al. (1990). "A ratio vegetation index adjusted for soil brightness." International Journal of Remote Sensing **VOL. II, No.5, 727-740**.

Malenovsky, Z., E. Martin, et al. (2008). "Influence of woody elements of a Norway spruce canopy on nadir reflectance simulated by the DART model at very high spatial resolution." Remote Sensing of Environment **112**(1): 1-18.

Malenovský, Z. and L. H. a. R. Zurita-Milla b, c, E. Martin d, M. E. Schaepman b, J.P. Gastellu-Etchegorry d, R. Pokorný a, J.G.P.W. Clevers b (2007). "Retrieval of coniferous canopy chlorophyll content from high spatial resolution hyperspectral data."

Malhi, Y. (2002). "Carbon in the Atmosphere and Terrestrial Biosphere in the 21st Century." Philosophical Transactions: Mathematical, Physical and Engineering Sciences **360**(1801): 2925-2945.

Malizia, A. (2003). "Host tree preference of vascular epiphytes and climbers in a subtropical montane cloud forest of northwest Argentina." Selbyana, **Vol. 24, (No. 2) 196-205**

Marchand, P. and G. Houle (2006). "Spatial patterns of plant species richness along a forest edge: What are their determinants?" Forest Ecology and Management **223**(1-3): 113-124.

Mazerolle, M. J. (2008). "Making sense out of Akaike's Information Criterion (AIC): its use and interpretation in model selection and inference from ecological data. Retrieved Jan 2008 from http://archimede.bibl.ulaval.ca/archimede/files/0471a76c-bfab-4cb4-b7e7-17d56094c809/apa.html."

McElhinny, C., P. Gibbons, et al. (2005). "Forest and woodland stand structural complexity: Its definition and measurement." Forest Ecology and Management **218**(1-3): 1-24.

McKelvey, R. and W. Zavoina (1994). "A statistical model for the analysis of ordinal level dependent variables." Journal of Mathematical Sociology **4: 103-120 Discusses polytomous and ordinal logits.** .

McNab, W. H. (1989). "Terrain Shape Index: Quantifying Effect of Minor Landforms on Tree Height." Forest Science **Vol. 35, No. 1, pp. 91-104**.

Meer, F. V. D., W. Bakker, et al. (2001). "Spatial scale variations in vegetation indices and above-ground biomass estimates: implications for MERIS." International Journal of Remote Sensing **2001, vol. 22, no. 17, 3381–3396**.

Mesquita, R. C. G., P. Delamônica, et al. (1999). "Effect of surrounding vegetation on edge-related tree mortality in Amazonian forest fragments " Biological Conservation **Volume 91**(Issues 2-3, December 1999, Pages 129-134).

MINITERE/RWANDA (2003). "National strategy and action plan for the conservation of biodiversity in Rwanda " MINITERE/Kigali.

Montes, F., A. Rubio, et al. (2007). "Characterization of the spatial structure of the canopy in Pinus silvestris L. stands in Central Spain from hemispherical photographs." Forest Ecology and Management **In Press, Corrected Proof**.

Mucunguzi, P. (2007). "Diversity and distribution of hemi-epiphytes and facultative herbaceous epiphytes in Kibale National Park, Uganda." African Journal of Ecology **Afr. J. Ecol., 45 (Suppl. 1), 57–64**.

Mucunguzi, P. (2007b). "Diversity and distribution of vascular epiphytes in the forest lower canopy in Kibale National Park, western Uganda." African Journal of Ecology **Vol. 45 Page 120 December 2007** (Suppl. 3, Biodiversity Conservation and Community Development).

Mueller-Dombois, D. R. and H. Ellenberg (1974). "Aims and Methods of Vegetation Ecology." John Wiley and Sons pp.1-547.

Myers, G. P., A. C. Newton, et al. (2000). "The influence of canopy gap size on natural regeneration of Brazil nut (Bertholletia excelsa) in Bolivia." Forest Ecology and Management **127**(1-3): 119-128.

Nagelkerke, N. J. D. (1991). "A note on a general definition of the coefficient of determination." Biometrika **Vol. 78, No. 3: 691-692**(Covers the two measures of R-square for logistic regression which are found in SPSS output.).

Nelder, J. A. and R. W. M. Wedderburn (1972). "Generalized Linear Models " Journal of the Royal Statistical Society **Series A(General)135,3,370-384**.

Newmark, W. D. (2001). "Tanzanian Forest Edge Microclimatic Gradients: Dynamic Patterns." Biotropica **33 (1), 2–11.** .

Nicholls, A. O. (1989). "How to Make Biological Surveys Go Further with Generalised Linear Models " Biological Conservation **50 (1989)51-75**.

Nieder, J., J. Prosperí, et al. (2001). "Epiphytes and their contribution to canopy diversity." Plant Ecology **153**(1): 51-63.

Noss, R. F. (1999). "Assessing and monitoring forest biodiversity: A suggested framework and indicators." Forest Ecology and Management **115**(2-3): 135-146.

Padmawathe, R., Q. Qureshi, et al. (2004). "Effects of selective logging on vascular epiphyte diversity in a moist lowland forest of Eastern Himalaya, India." Biological Conservation **119**(1): 81-92.

Pampel, F. C. (2000). "Logistic regression: A primer. Sage Quantitative Applications in the Social Sciences Series #132." Thousand Oaks, CA: Sage Publications **Pp. 35-38**(provide an example with commented SPSS output.).

Pears, N. V. (1968). "Some Recent Trends in Classification and Description of Vegetation." Geografiska Annaler. Series A, Physical Geography **50**(3): 162-172.

Pepe, M. S. (2000). "An Interpretation for the ROC Curve and Inference Using GLM Procedures." Biometrics, **Vol. 56, No. 2. (Jun., 2000), pp. 352-359**.

Piazzi, L., S. Acunto, et al. (2000). "Mapping of Posidonia oceanica beds around Elba Island (western Mediterranean) with integration of direct and indirect methods." Oceanologica Acta **23**(3): 339-346.

Pickering, C. M. and W. Hill (2006). "Impacts of recreation and tourism on plant biodiversity and vegetation in protected areas in Australia." Journal of Environmental Management **In Press, Corrected Proof**.

Plumptre, A. J., T. R. B. Davenport, et al. (2007). "The biodiversity of the Albertine Rift." Biological Conservation **134**(2): 178-194.

Plumptre, A. J., M. Masozera, et al. (2002). "Biodiversity surveys of the Nyungwe Forest Reserve in S.W. Rwanda." WCS Working Paper no . 1 9.

Rainforestlive (2007). "Canopy layers of tropical rainforest retrieved July 2007 from:http://www.rainforestlive.org.uk/media/Images/LAYER500copy.jpg."

Reitz, K. (2001). "Indigenous Peoples in Resistance: History with an Anthropological Perspective." Latin American Perspectives **28**(6): 85-87.

Richards, P. W. (1979). "The tropical rainforest: An Ecological Study." Botany School Cambridge **Vol 2**: p.559(389 - 417).

Richards, P. W. (1996). "The tropical rain forest." Cambridge University Press **2nd ed**: p559 (389 - 417).

Richardson, A. J. W. C. L. (1977). "Distinguishing Vegetation from Soil Background Information." Photogrammetric Engeneering and Remote Sensing, **43, 1541-1552**.

Rizinjirabake, F. (2002). "Contribution à l'étude de la régénération naturelle des arbres dans la forêt de montagnes de Nyungwe." Mémoire de licence en biologie, UNR, Butare: 101 p.

Roberts, D. A., M. Keller, et al. (2003). "Studies of land-cover, land-use, and biophysical properties of vegetation in the Large Scale Biosphere Atmosphere experiment in Amazonia." Remote Sensing of Environment **87**(4): 377-388.

Rouse, J. W. H. J. R. S. R. H. a. D. D. W. (1974). "Monitoring vegetation system in the Great Plains with ERTS, Sympoosium Proceeding. ." NASA Goddard Space Flight Center **3ed ERTS-1,1,1,309-317**.

Row, J. R., G. Blouin-Demers, et al. (2007). "Demographic effects of road mortality in black ratsnakes (Elaphe obsoleta)." Biological Conservation **137**(1): 117-124.

Schedlbauer, J. L., B. Finegan, et al. (2007). "Rain Forest Structure at Forest-Pasture Edges in Northeastern Costa Rica." Biotropica **Volume 39 Issue 5 Page 578-584, September 2007**

Schieck, J., K. Lertzman, et al. (1995). "Effects of Patch Size on Birds in Old-Growth Montane Forests " Conservation Biology **Vol. 9, No. 5 (Oct., 1995), pp. 1072-1084**.

Schleppi, P., M. Conedera, et al. (2007). "Correcting non-linearity and slope effects in the estimation of the leaf area index of forests from hemispherical photographs." Agricultural and Forest Meteorology **144**(3-4): 236-242.

Schlerf, M., C. Atzberger, et al. (2005). "Remote sensing of forest biophysical variables using HyMap imaging spectrometer data." Remote Sensing of Environment **95**(2): 177-194.

Scobell, S. and S. Schultz (2005). "GIS and Path Analysis: Examining Associations Between the Birds, the Bees, and Plant Sex in Echinocereus coccineus (Cactaceae)." USDA Forest Service Proceedings **RMRS-P-36**.

Shi;, P. and C.-L. Tsai (1998). "A Note on the Unification of the Akaike Information Criterion." Journal of the Royal Statistical Society. **60, No. 3.(1998), pp. 551-558.**

Sim-Siam, M., P. Carvalho, et al. (2000). "Cryptogamic epiphytes as indicators of air quality around an industrial complex in the Tagus valley, Portugal. Factor analysis and environmental variables." Cryptogamie Bryologie **21**(2): 153-170.

Sir Michael Blundell, K. B. E. (1987). "Collins Guide to the WILD FLOWERS OF EAST AFRICA." London: 464 pages.

Sokal, R. R. and F. J. Rohlf (1981). Biometry : the principles and practice of statistics in biological research. New York, W.H. Freeman.

Sokal, R. R. and F. J. Rohlf (1995). Biometry : the principles and practice of statistics in biological research. New York, W.H. Freeman.

Song, C. and C. E. Woodcock (2002). "The spatial manifestation of forest succession in optical imagery: The potential of multiresolution imagery." Remote Sensing of Environment **82**(2-3): 271-284.

Sterck, F. J. and F. Bongers (2001). "Crown Development in Tropical Rain Forest Trees: Patterns with Tree Height and Light Availability." The Journal of Ecology **Vol. 89, No. 1. (Feb., 2001), pp. 1-13.**

Storz, M. (1983). "La forêt naturelle de Nyungwe et sa faune." (PPF Kibuye, 56 p.).

Sun, C., B. Kaplin, et al. (1996). "Tree phenology in tropical montane forest in Rwanda " Biotropica **28:668-681**.

Tanner, D. and J. Perry (2006). "Road effects on abundance and fitness of Galapagos lava lizards (Microlophus albemarlensis)." Journal of Environmental Management **In Press, Corrected Proof**.

Thenkabail, P. S., J. Hall, et al. (2003). "Detecting floristic structure and pattern across topographic and moisture gradients in a mixed species Central African forest using IKONOS and Landsat-7 ETM+ images." International Journal of Applied Earth Observation and Geoinformation **4**(3): 255-270.

Trexler, J. C. and J. Travis (1993). "Nontraditional Regression Analyses." Ecology **Vol. 74, No. 6. (Sep., 1993), pp. 1629-1637.**

Troupin, G. (1978). "Flore du Rwanda, Spermatophytes, Volume I, ." Musée Royal de l'Afrique Centrale - Tervuren, Belgique.

Troupin, G. (1985). "Flore du Rwanda, Spermatophytes, Volume III.,." Institut National de Recherche Scientifique, Butare, Rwanda.

Troupin, G. (1988). "Flore du Rwanda, Spermatophytes, Volume IV.,." Institut National de Recherche Scientifique, Butare, Rwanda.

Tucker, C. J. (1979). "Red and photographic infrared linear combinations for monitoring vegetation." Remote Sensing of Environment **Volume 8,127-150**

UCLA (2008). " "Stata Data Analysis Examples: Logistic Regression Power Analysis retrieved Jan. 2008 from http://www.ats.ucla.edu/stat/Stata/dae/logit_power.htm."

UNEP (2002). "The Great Apes the Road Ahead." Global Methodology for Mapping Human Impacts on the Biosphere: p.30.

Watterson, N. A. and J. A. Jones (2006). "Flood and debris flow interactions with roads promote the invasion of exotic plants along steep mountain streams, western Oregon." Geomorphology **78**(1-2): 107-123.

Weber, N. A. (1959). "Isothermal Conditions in Tropical Soil." Ecology **40**(1): 153-154.

Whitmore, T. C. (1998). "An introduction to tropical rain forests." Oxford University Press **2nd ed.**

Willcox, A. S. and D. M. Nambu (2007). "Wildlife hunting practices and bushmeat dynamics of the Banyangi and Mbo people of Southwestern Cameroon." Biological Conservation **134**(2): 251-261.

Williams-Linera, G. and R. O. Lawton (1989). "The ecology of hemi epiphytes in Forest canopies. In: Forest Canopies (Eds M. D.

Lowman and N. M. Nadkarni). Academic Press, New York."

Wu, C.-C., C.-C. Tsui, et al. (2007). "Mineral nutrient status of tree species in relation to environmental factors in the subtropical rain forest of Taiwan." Forest Ecology and Management **239**(1-3): 81-91.

WWF (2007). "Tropical Rainforest". Retrieved June 2007 from http://www.panda.org/news_facts/education/high_school/habitats/tropical_rainforest/index.cfm."

Zartman, C. E. and H. E. M. Nascimento (2006). "Are habitat-tracking metacommunities dispersal limited? Inferences from abundance-occupancy patterns of epiphylls in Amazonian forest fragments." Biological Conservation **127**(1): 46-54.

Zhang, Q., G. Pavlic, et al. (2004). "Deriving stand age distribution in boreal forests using SPOT VEGETATION and NOAA AVHRR imagery." Remote Sensing of Environment **91**(3-4): 405-418.

Zhao, C., Z. Nan, et al. (2006). "GIS-assisted modelling of the spatial distribution of Qinghai spruce (Picea crassifolia) in the Qilian Mountains, northwestern China based on biophysical parameters." Ecological Modelling **191**(3-4): 487-500.

Zhu, Y., X. Yao, et al. (2008). "Analysis of common canopy vegetation indices for indicating leaf nitrogen accumulations in wheat and rice." International Journal of Applied Earth Observation and Geoinformation **10**(1): 1-10.

Zimmerman, J. K. and I. C. Olmsted (1992). "Host Tree Utilization by Vascular Epiphytes in a Seasonally Inundated Forest (Tintal) in Mexico " Biotropica **Vol. 24, No. 3 (Sep., 1992), pp. 402-407**.

7. Appendices

Appendix 1: Fieldwork preparation/Field data collection form

<table>
<tr><td rowspan="4">Identification

Date:……../…../2007
Road type:………………
Transect:………………..
Plot: ………………………</td><td colspan="2">Lat.: Start: 97………. End: 97…….</td></tr>
<tr><td colspan="2">Long.: Start: …………..End: ……….</td></tr>
<tr><td>Slope:</td><td>Aspect:</td></tr>
<tr><td></td><td></td></tr>
</table>

<table>
<tr><td colspan="9">Forest layer type</td></tr>
<tr><td></td><td>Emergency</td><td>Trees</td><td>Under storey</td><td>Shrub</td><td colspan="4">floor</td></tr>
<tr><td>Cover (%)</td><td></td><td></td><td></td><td></td><td>BS</td><td>Litter</td><td>Stones</td><td>Grass</td></tr>
<tr><td>Height (m)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Remarks
Canopy height:</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

<table>
<tr><td colspan="3">Epiphytes</td></tr>
<tr><td>Present (species)</td><td>Abundances</td><td>Remarks (tree species, roadside…)</td></tr>
<tr><td></td><td></td><td rowspan="5"></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
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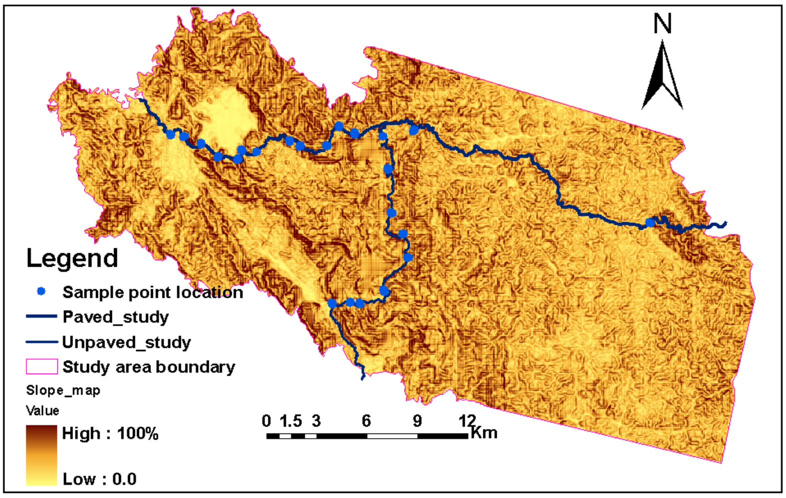
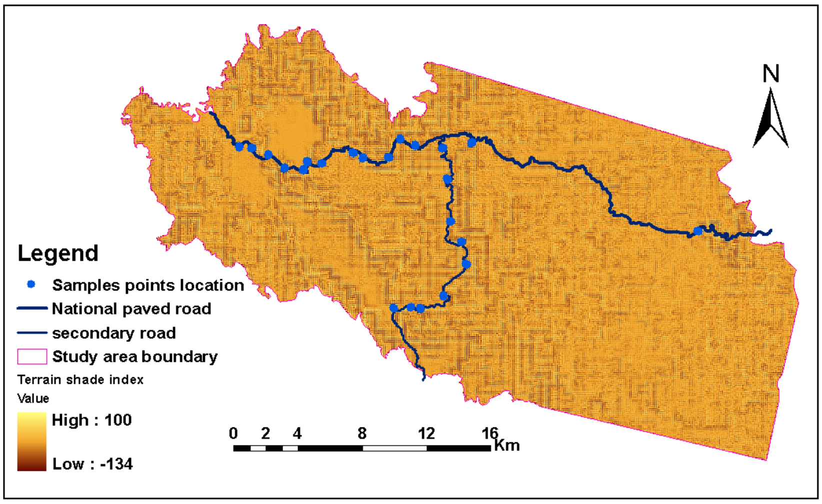
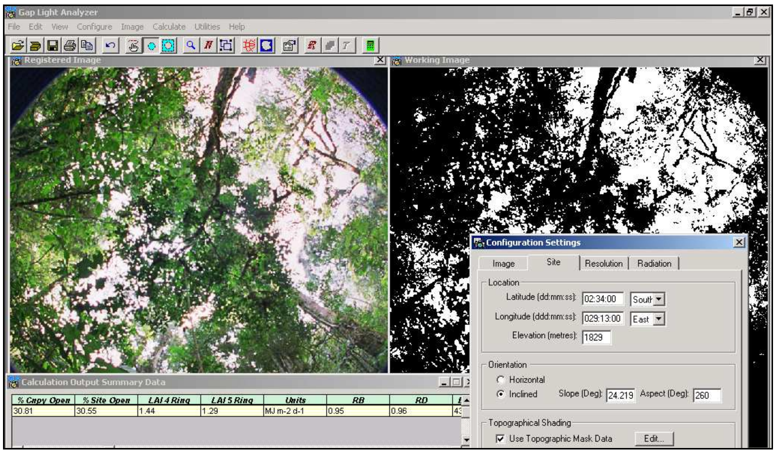
Appendix 2: GIS and RS data processing/Slope map of study area



Appendix 3: GIS and RS data processing /Terrain shade index map of study area



Appendix 4: GIS and RS data processing /Hemispherical photograph analysis under GLA software



Calculation Output Summary Data

% Cnpy Open	% Site Open	LAI 4 Ring	LAI 5 Ring	Units	RB	RD
30.81	30.55	1.44	1.29	MJ m-2 d-1	0.95	0.96

Location

Latitude (dd:mm:ss): 02:34:00 South

Longitude (ddd:mm:ss): 029:13:00 East

Elevation (metres): 1829

Orientation

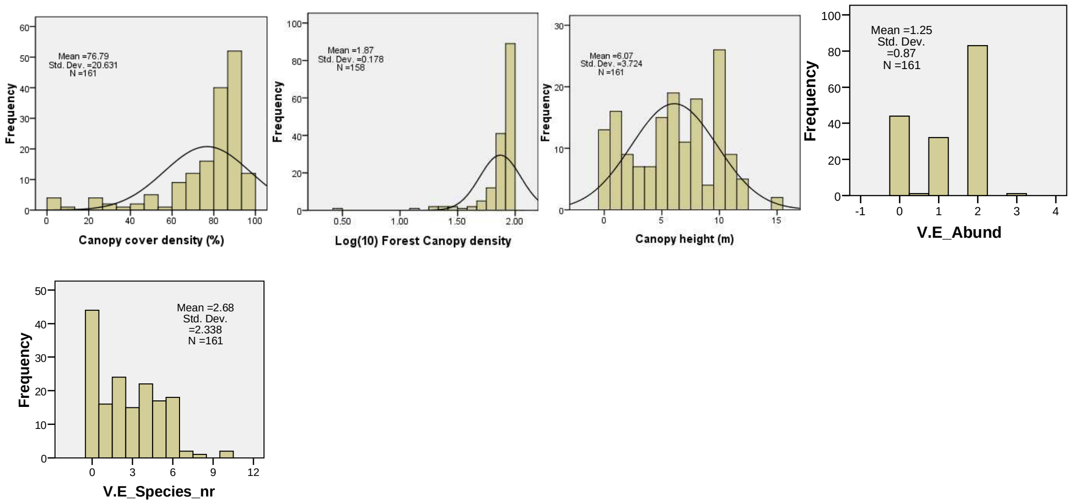
○ Horizontal

● Inclined Slope (Deg): 24.219 Aspect (Deg): 260

Topographical Shading

☑ Use Topographic Mask Data

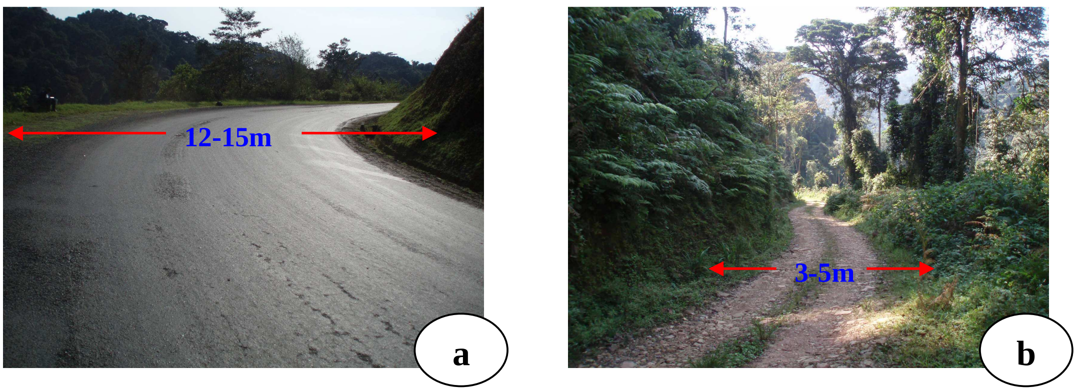
Appendix 5: Data exploration/Descriptive graphs



Appendix 6: Pearson correlation matrix between forest structure and vascular biodiversity variables and all environmental and RS variables

V.E_Snr	**V.E_Snr**	**V.E_Ab**	**V.E_PA**	**FCD**	**FCH**	**Dist**	**Alt**	**Em_H**	**Em_C**	**Tr_H**	**TR_C**	**Und_H**	**Und_C**
V.E_Ab	1.00												
V.E_PA	0.74	1.00											
FCD	0.71	0.89	1.00										
FCH	0.47	0.57	0.59	1.00									
Dist	0.49	0.65	0.61	0.59	1.00								
Alt	0.23	0.33	0.24	0.14	0.39	1.00							
Slope	-0.41	-0.43	-0.38	-0.19	-0.22	0.00	1.00						
Rad	-0.12	-0.13	-0.10	-0.09	-0.12	0.01	-0.08						
Aspect	-0.46	-0.59	-0.57	-0.78	-0.61	-0.12	0.38						
TSI	-0.13	-0.09	-0.10	0.00	-0.05	-0.01	0.05						
Em_H	-0.07	-0.29	-0.26	-0.15	-0.18	0.02	0.30						
Em_C	0.41	0.44	0.41	0.33	0.57	0.27	-0.21	1.00					
Tr_H	0.43	0.44	0.38	0.30	0.47	0.30	-0.17	0.84	1.00				
TR_C	0.14	0.28	0.33	0.35	0.46	0.02	-0.09	-0.10	-0.22	1.00			
Und_H	0.14	0.20	0.23	0.34	0.37	-0.02	-0.05	-0.21	-0.34	0.77	1.00		
Und_C	0.25	0.29	0.33	0.47	0.33	-0.08	-0.07	0.09	0.10	0.07	0.10	1.00	
B1	0.05	0.13	0.14	0.38	0.08	-0.13	0.13	-0.14	-0.12	-0.04	-0.04	0.56	1.00
B2	-0.23	-0.28	-0.32	-0.31	-0.27	-0.23	0.05	-0.18	-0.12	-0.16	-0.12	-0.16	0.01
B3	-0.24	-0.28	-0.33	-0.23	-0.24	-0.23	0.13	-0.14	-0.11	-0.13	-0.06	-0.15	0.03
B4	-0.29	-0.31	-0.34	-0.38	-0.25	-0.12	0.13	-0.17	-0.09	-0.11	-0.17	-0.21	-0.17
B5	-0.13	-0.14	-0.15	-0.15	-0.15	-0.33	0.01	-0.03	-0.01	-0.07	-0.07	-0.06	-0.07
B6	-0.23	-0.22	-0.24	-0.19	-0.17	-0.33	0.01	-0.05	-0.05	-0.15	-0.07	-0.11	-0.04
B7	-0.19	-0.19	-0.20	-0.16	-0.17	-0.40	-0.06	-0.06	-0.07	-0.09	-0.04	-0.04	-0.04
B8	-0.22	-0.27	-0.25	-0.21	-0.22	-0.39	0.24	-0.12	-0.11	-0.11	-0.06	-0.02	0.05
B9	-0.22	-0.27	-0.28	-0.20	-0.23	-0.35	0.25	-0.10	-0.10	-0.15	-0.06	-0.09	0.02
DVI	-0.30	-0.32	-0.31	-0.17	-0.22	-0.26	0.38	-0.11	-0.14	-0.19	-0.07	-0.04	0.10
NDVI	-0.26	-0.27	-0.29	-0.36	-0.21	-0.08	0.11	-0.15	-0.07	-0.09	-0.17	-0.20	-0.19
PVI	-0.18	-0.16	-0.15	-0.24	-0.09	0.00	0.08	-0.09	-0.02	-0.01	-0.14	-0.13	-0.22
RVI	-0.11	-0.10	**-0.09**	-0.21	-0.07	0.05	0.03	-0.07	-0.01	-0.02	-0.13	-0.10	-0.20
RSR	-0.18	-0.18	-0.17	-0.27	-0.14	-0.01	0.05	-0.11	-0.03	-0.05	-0.17	-0.15	-0.21
SAVI	0.04	0.05	**0.08**	0.05	0.13	0.37	0.02	0.00	0.00	0.07	0.01	0.01	-0.04
SAVI2	-0.18	-0.16	-0.15	-0.24	-0.09	0.00	0.08	-0.09	-0.02	-0.02	-0.14	-0.13	-0.22
TSAVI	-0.20	-0.20	-0.20	-0.29	-0.15	-0.02	0.06	-0.12	-0.04	-0.06	-0.17	-0.16	-0.21

Appendix 7: Forest gap created by road (a) Paved road; (b) secondary road in Nyungwe rainforest



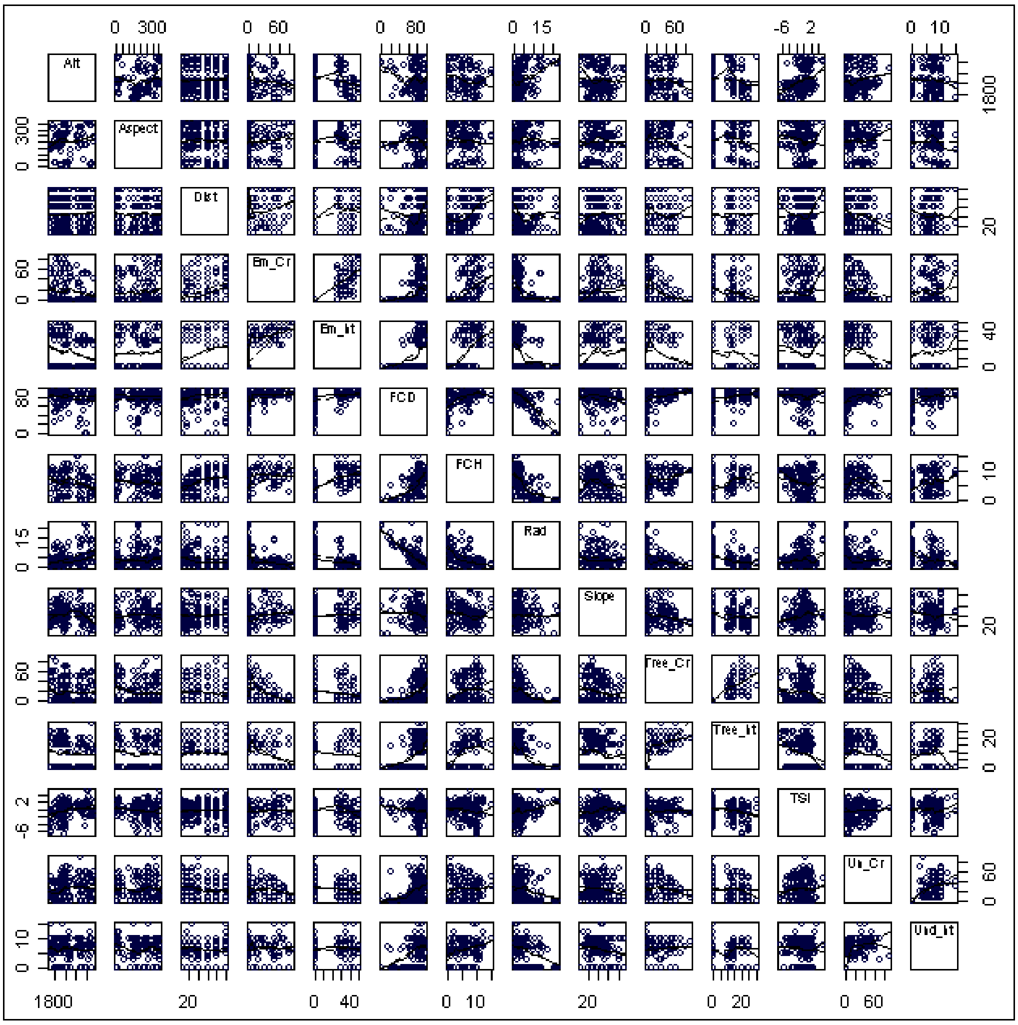
Appendix 8: Vascular epiphyte inventoried during transect work

Family	**Species inventoried**	**Paved road**	**Secondary road**
1. **Aspleniaceae**	Asplenium inaequilaterale		
	Asplenium lobatum	■	
	asplenium mannii		
	Asplenium megalura		
	Asplenium rutifolium		■
	Asplenium sandersonii		
	Asplenium sp		■
	asplenium theciferum var. concinnum		■
	asplenium variens		■
2. **Orchidaceae**	Angraecum humile	■	
	Angraecum infundibulare	■	
	Aerangis sp	■	
	Bulbophyllum cochleatum	■	
	Bulbophyllum comatum	■	
	Bulbophyllum sp		
	Bulbophyllum unifoliafum	■	
	Chamacangis odoratissima		
	Cyrtorchis arcuata		
	Cyrtorchis ringens		■
	Cyrtorchis sp		■
	Diaphananthe bidens	■	
	Diaphananthe bilobata	■	
	Diaphananthe burttii	■	
	Diaphananthe densiflora	■	
	Diaphananthe fragrantissima		
	Diaphananthe globulosocalcarata		■
	Diaphananthe rutila	■	
	Diaphananthe sp		
	Epidendrum ibaguense	■	
	Europhia sp.	■	
	Nephrangis filiformis	■	
	Polystachya bicarinata	■	
	Polystachya lindblomii		■
	Polystachya pachychila		■
	Polystachya polychaete	■	
	Polystachya sp		
	Polystachya troupiniana		
	Polystachya virginea		
	Summerhayesia rwandensis	■	
	Tridactyle anthomaniaca	■	
	Tridactyle sp	■	
	Tridactyle virgula		
3. **Polypodiaceae**	Loxogramma lanceolata		
	Loxogramma sp.		
	Micrograma lanceolata	■	
	Micrograma sp.		
	Oleandra distenta		
	Pleopeltis macrocarpa	■	
	Pyrrosia lanceolata		
	Pyrrosia schimperiana	■	

4. **Grammitidaceae**	Grammitis sp.		
	Xiphopteris flabelliformis		
	Zygophlebia sp.	▨	
5. **Vittariaceae**	Vittaria elongata		▨
	Vittaria isoetifolia		▨
	Vittaria sp		
	Vittaria volkensii		
6. **Piperaceae**	Peperomia retusa		
	Peperomia sp.	▨	
	Peperomia tetraphylla		
7. **Woodsiaceae**	Athyrium sp		▨
	Woodsia burgessiana		
8. **Thelypteridaceae**	Amauropelta bergiana		▨
	Menisorus pauciflorus		▨
	Methathelypteris fragilis	▨	
9. **Oleandraceae**	Nephrolepsis sp		
10. **Lomariopsidaceae**	Elaphoglossum sp.		▨
11. **Dennstaedtiaceae**	Blotiella crenata		
	Odontosoria sp		▨
	sphenomeris afra		▨
12. **Hymenophyllaceae**	Mecodium kuhnii		
	Sphaerocionium capillare		▨
	Vandenboschia melanotricha		▨
13. **Lycopodiaceae**	Hyperzia sp		▨
14. **Dryopteridaceae**	Phanerophlebia caryotidea		
	Phanerophlebia sp		
15. **Begoniaceae**	Begonia sp	▨	

- Was presents around that road category :
- Was not presents around that road category : ▨

Appendix 9: Variable selection/Parwise scatterplots of environmental variables

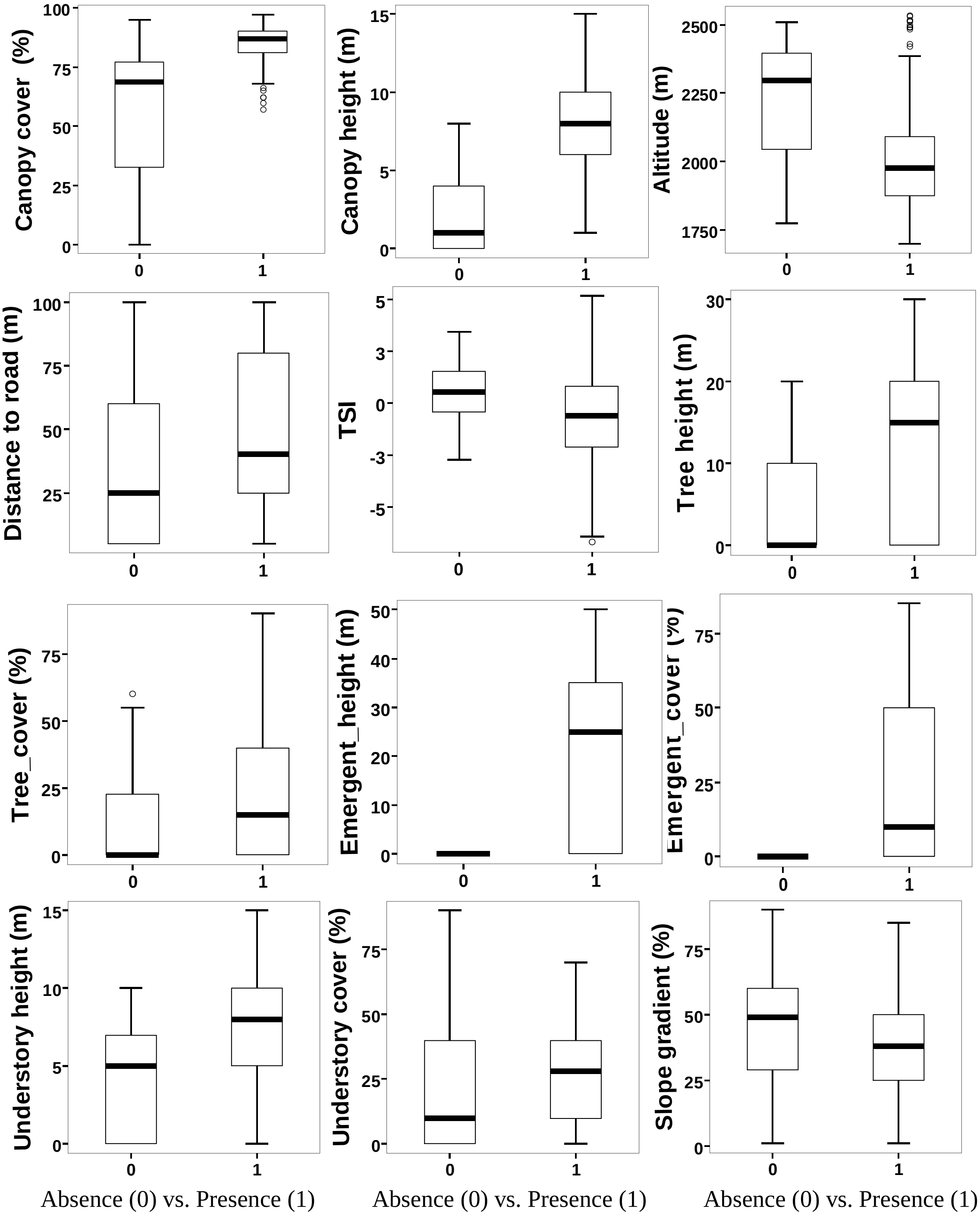


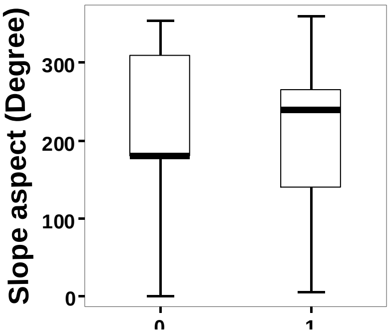
Environmental predictors are plotted in the following sequence: Alt: altitude, Aspect: slope aspect, Dist: distance to road edge, Em_Cr: emergent cover, Em_ht: emergent height, FCD: forest canopy density, FCH: forest canopy height, Rad: radiation, Slope: slope gradient, Tree_Cr: tree cover, Tree_ht: tree height, TSI: terrain shade index, Un_Cr: understory cover and Und_ht: understory height

Appendix 10: Spearman correlation matrix between environmental variable

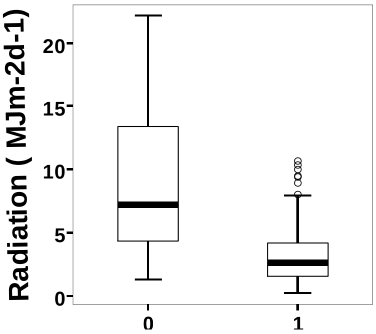
V.E_PA	V.E_PA	FCD	FCH	Dist	Altit	Slope	Rad	Aspect	TSI	Em_H	Em_C	Tr_H	Tr_C	Und_H	Und_C
FCD	1.00														
FCH	0.54	1.00													
Dist	0.61	0.61	1.00												
Altit	0.26	0.36	0.42	1.00											
Slope	-0.35	-0.12	-0.18	0.01	1.00										
Rad	-0.11	-0.20	-0.16	0.04	-0.07	1.00									
Aspect	-0.54	-0.68	-0.62	-0.26	0.31	-0.04	1.00								
TSI	-0.09	-0.05	-0.03	0.01	0.12	-0.01	0.07	1.00							
Em_H	-0.26	-0.10	-0.17	0.04	0.28	0.26	0.07	-0.12	1.00						
Em_C	0.41	0.34	0.56	0.26	-0.21	0.10	-0.45	0.01	-0.05	1.00					
Tr_H	0.41	0.33	0.55	0.32	-0.15	0.14	-0.46	0.08	0.03	0.94	1.00				
Tr_C	0.33	0.33	0.45	0.03	-0.11	-0.15	-0.35	-0.02	-0.21	-0.10	-0.18	1.00			
Und_H	0.27	0.36	0.42	0.01	0.00	-0.19	-0.35	-0.05	-0.11	-0.16	-0.24	0.87	1.00	1.00	
Und_C	0.32	0.31	0.29	-0.08	-0.05	-0.11	-0.24	-0.02	-0.09	0.08	0.09	0.08	0.06	0.58	1.00

Appendix 11: Grouped boxplots graphs of each environmental variables by presence/absence data of vascular epiphyte





Absence (0) vs. Presence (1)



Absence (0) vs. Presence (1)

Appendix 12: Logistic regression output

A. Backward stepwise logistic regression out put: W-statistics for predictor variables weight

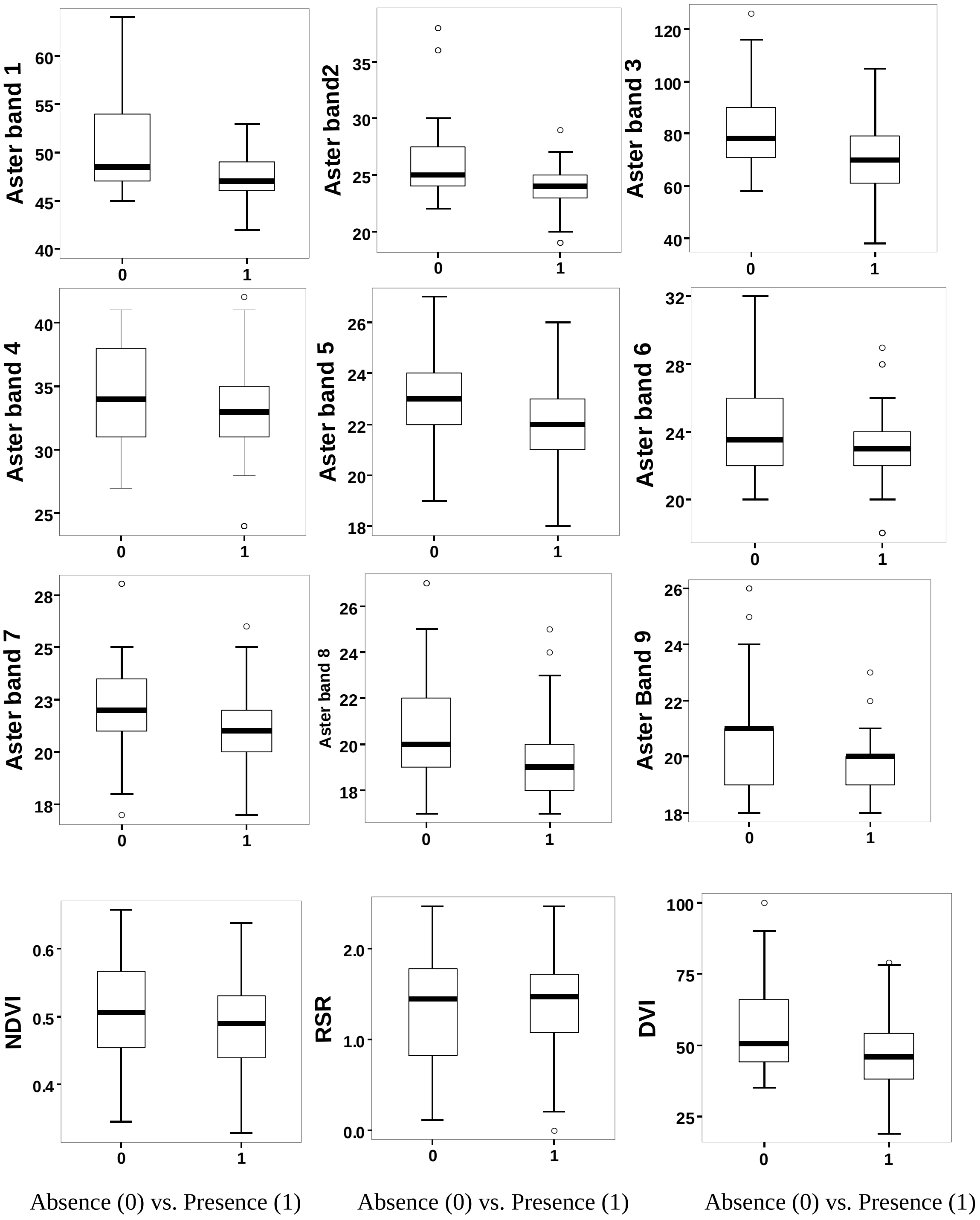
								95% CI of Exp(B)	
	Predictor	**B**	**SE**	**Wald**	**df**	**Sig.**	**Exp(B)**	**Lower**	**Upper**
Step 1	Canopy cover	0.087	0.031	**7.793**	1	0.005	1.091	1.026	1.159
	Canopy height	0.088	0.191	0.214	1	0.643	1.092	0.752	1.587
	Distance to road	0.028	0.012	5.562	1	0.018	1.028	1.005	1.052
	Altitude	-0.005	0.002	8.700	1	0.003	0.995	0.992	0.998
	Radiation	0.111	0.112	0.977	1	0.323	1.117	0.897	1.391
	TSI	-0.783	0.261	8.989	1	0.003	0.457	0.274	0.762
	Emergent height	-0.005	0.038	0.015	1	0.904	0.995	0.925	1.071
	Emergent cover	0.077	0.042	3.433	1	0.064	1.080	0.996	1.172
	Tree height	0.096	0.068	2.032	1	0.154	1.101	0.965	1.257
	Tree cover	0.004	0.026	0.026	1	0.871	1.004	0.955	1.056
	Understory height	0.161	0.092	3.051	1	0.081	1.174	0.981	1.407
	Constant	0.361	2.754	0.017	1	0.896	1.434		
Step 2	Canopy cover	0.087	0.031	**7.943**	1	0.005	1.091	1.027	1.159
	Canopy height	0.080	0.177	0.203	1	0.652	1.083	0.766	1.531
	Distance to road	0.028	0.012	5.562	1	0.018	1.028	1.005	1.052
	Altitude	-0.005	0.002	8.762	1	0.003	0.995	0.992	0.998
	Radiation	0.111	0.112	0.982	1	0.322	1.117	0.898	1.390
	TSI	-0.784	0.262	8.970	1	0.003	0.457	0.273	0.763
	Emergent cover	0.075	0.037	4.033	1	0.045	1.078	1.002	1.159
	Tree height	0.098	0.067	2.168	1	0.141	1.103	0.968	1.256
	Tree cover	0.004	0.026	0.025	1	0.875	1.004	0.955	1.056
	Understory height	0.162	0.092	3.107	1	0.078	1.176	0.982	1.408
	Constant	0.352	2.752	0.016	1	0.898	1.422		
Step 3	Canopy cover density	0.087	0.031	**7.939**	1	0.005	1.091	1.027	1.159
	Canopy height	0.082	0.176	0.215	1	0.643	1.085	0.768	1.533
	Distance to road	0.028	0.012	5.618	1	0.018	1.028	1.005	1.052
	Altitude	-0.005	0.002	9.001	1	0.003	0.995	0.992	0.998
	Radiation	0.106	0.108	0.968	1	0.325	1.112	0.900	1.374
	TSI	-0.781	0.261	8.983	1	0.003	0.458	0.275	0.763

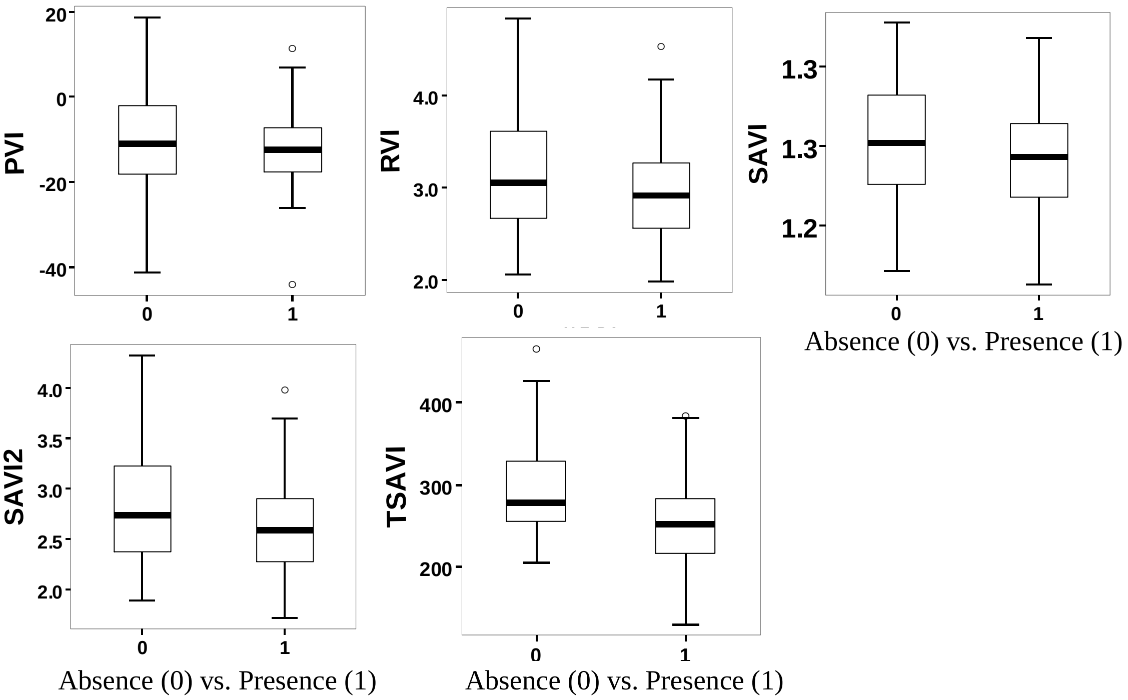
	Emergent cover	0.074	0.037	4.042	1	0.044	1.077	1.002	1.157
	Tree height	0.104	0.054	3.682	1	0.055	1.110	0.998	1.234
	Understory height	0.161	0.092	3.081	1	0.079	1.174	0.981	1.406
	Constant	0.293	2.731	0.011	1	0.915	1.340		
Step 4	Canopy cover	0.090	0.030	**8.685**	1	0.003	1.094	1.031	1.161
	Distance to road	0.028	0.012	5.980	1	0.014	1.029	1.006	1.052
	Altitude	-0.005	0.002	9.826	1	0.002	0.995	0.992	0.998
	Radiation	0.104	0.108	0.925	1	0.336	1.109	0.898	1.370
	TSI	-0.792	0.262	9.142	1	0.002	0.453	0.271	0.757
	Emergent cover	0.087	0.027	10.37	1	0.001	1.091	1.034	1.150
	Tree height	0.120	0.042	8.171	1	0.004	1.128	1.039	1.225
	Understory height	0.168	0.090	3.462	1	0.063	1.183	0.991	1.413
	Constant	0.520	2.696	0.037	1	0.847	1.682		
Step 5	Canopy cover	0.074	0.025	**8.746**	1	0.003	1.077	1.025	1.132
	Distance to road	0.029	0.012	6.286	1	0.012	1.030	1.006	1.053
	Altitude	-0.004	0.001	9.780	1	0.002	0.996	0.993	0.998
	TSI	-0.758	0.253	8.972	1	0.003	0.469	0.286	0.770
	Emergent cover	0.081	0.026	9.475	1	0.002	1.085	1.030	1.143
	Tree height	0.104	0.038	7.695	1	0.006	1.110	1.031	1.195
	Understory height	0.162	0.091	3.164	1	0.075	1.175	0.984	1.405
	Constant	0.990	2.650	0.140	1	0.709	2.692		
Step 6	Canopy cover	0.087	0.024	**13.21**	1	0.000	1.091	1.041	1.144
	Distance to road	**0.025**	**0.011**	**4.96**	1	**0.026**	**1.026**	**1.003**	**1.049**
	Altitude	-0.004	0.001	8.688	1	0.003	0.996	0.994	0.999
	TSI	-0.707	0.239	8.788	1	0.003	0.493	0.309	0.787
	Emergent cover	0.077	0.025	9.563	1	0.002	1.080	1.029	1.134
	Tree height	0.088	0.035	6.380	1	0.012	1.092	1.020	1.169
	Constant	0.206	2.656	0.006	1	0.938	1.229		

B. Forward stepwise logistic regression out put

								95% CI of Exp(B)	
	Predictor	**B**	**SE**	**Wald**	**df**	**Sig.**	**Exp(B)**	**Lower**	**Upper**
Step 1	Canopy height	.550	.087	**40.168**	1	.000	1.734	1.462	2.055
	Constant	-1.624	.408	15.860	1	.000	.197		
Step 2	Canopy height	.534	.091	**34.690**	1	.000	1.705	1.428	2.036
	Altitude	-.003	.001	10.298	1	.001	.997	.995	.999
	Constant	5.198	2.118	6.024	1	.014	180.954		
Step 3	Canopy cover	.070	.023	**9.241**	1	.002	1.072	1.025	1.122
	Canopy height	.362	.099	**13.447**	1	.000	1.436	1.184	1.743
	Altitude	-.004	.001	11.052	1	.001	.996	.994	.999
	Constant	1.544	2.439	.401	1	.527	4.682		

Appendix 13: Grouped boxplots graphs of each aster image derived variables by presence/absence data of vascular epiphyte




PVI
20
0
-20
-40
0
1
RVI
4.0
3.0
2.0
0
1
SAVI
1.3
1.3
1.2
0
1
Absence (0) vs. Presence (1)
SAVI2
4.0
3.5
3.0
2.5
2.0
0
1
Absence (0) vs. Presence (1)
TSAVI
400
300
200
0
1
Absence (0) vs. Presence (1)