Landform Controls on the Distribution of Forest Canopy Vascular Epiphyte in a Tropical Mountainous Rainforest using GIS and RS:
Case Study of Nyungwe National Park, South-Western Rwanda.

Elias Nyandwi
Geographic Information Systems and Remote Sensing Centre
National University of Rwanda
Po Box 212 Huye-Rwanda
Email: nyaneli@yahoo.fr ;enyandwi@nur.ac.rw; elias.nyandwi@cgisnur.org

Abstract

In the tropical mountainous rainforest, the forest canopy structure is highly correlated with local topography. However, the relationships of forest canopy structure with canopy vascular epiphyte (one of its unique biodiversity richness) is poorly described and yet to be established. This study aims at modelling the distribution of canopy vascular epiphyte diversity in the Nyungwe National Park of Rwanda. Canopy vascular epiphyte distributions were mapped by applying a logistic regression equation relating the presence/absence data to the parameters of surface shape.
The results indicated that there is a significant impact of terrain elevation and the geomorphic shape of the land surface (terrain shape index) on vascular epiphyte occurrence. Based on the most accurate logistic model assessed by the residual deviance information, the Akaike Information Criterion and the area under the Receiver Operating Characteristic Curve, the probability of vascular epiphytes to occur was predicted at 75 % level of accuracy. This confirms the role of elevation and landform to determine communities and site suitability in mountainous areas.
Keywords: Tropical rainforest, landform index, canopy structure, vascular epiphyte, spatial modeling.

1. Introduction

Geomorphology is becoming 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 (2003). The terrain shape index represents the average relative difference in elevation between the central pixel and its eight neighbours and offers important information when attempting to measure the influence of landforms changes on vegetation and climate. This is because elevation and exposition rather than soil types determine communities and site suitability in mountainous areas (Fontaine, Aerts et al. 2007)

Nyungwe tropical and mountainous rainforest landscapes consist of enumerable landforms of various sizes and shapes. Nyungwe rainforest regroups different forest categories according to the topographic gradient, Storz (1983) has proposed four different horizons, as summarized in Table 1. The spatial examination of landform variations is required to understand changes induced in forest structure and canopy lives. Tropical rainforests (TR) are home to two-thirds of all living animal and plant species on the planet. Over 70 % of the forest biological richness is related to the forest canopy, home to a unique flora and fauna not found in other layers of a forest. As such, the terrain shape index affects the epiphyte species distribution; which helps to understand changes induced in forest structure pattern.

Table 1: Altitudinal variation of vegetation in Nyungwe rainforest

Horizon	Vegetation type
Inferior zone (1400 -1600m)	Very tall and larges trees of 35 to 40 m. e.g: *Parinari excelsa*, *Newtonia buchananii*, *Symphonia globulifera*, *Entandrophragma excelsum*, *Albizia gummifera* and *Carapa grandiflora*.
Medium zone (1600-2250)	Normal height trees with 20-35m. e.g: *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 tree species are: *Podocarpus milanjianus*. Mosses and lichens are often presents
Subalpine zone (> 2500m)	Trees are very rare, short shrub species like *Philippia benguellensis* and grasses cover the area.

Epiphyte diversity in Nyungwe is very high with more than 100 species of orchids already identified, and several species are still unidentified in the area (Fischer 1997). From the 1980's, inventories of fauna and flora were completed by local and international researchers within Nyungwe forest with an emphasis on tree phenology and primate ecology. Until now, epiphyte, have been poorly surveyed (Plumptre, Davenport et al. 2007).

The aim of this study is to investigate the relationship between land surface shape and forest canopy vascular epiphyte occurrence in the Nyungwe rainforest.

2. Methods and Materials

2.1. *Study area*

The Nyungwe National Park is a mountainous rainforest in South-western Rwanda between 2°15' to 2°55' S and 29°00' to 29°30' E (see Figure 1). The park is located in the Albertine Rift; a series of mountain ranges beginning at the Ruenzori mountains in western Uganda and Democratic Republic of Congo (DRC), continuing south into the Lendu Plateau in Eastern DRC and contiguous with Kibira National Park in Burundi.

Temperatures at Nyungwe are rather generally cool (10-20°C) with a mean annual rainfall of 1,800 mm (Sun, Kaplin et al. 1996).

A major dry season occurs between July and August and a minor dry season takes place between December and January. The conservation area covers approximately 970 km^2 and includes vast stretches of forest spanning elevations between 1,400 and 2,950 m above sea level.

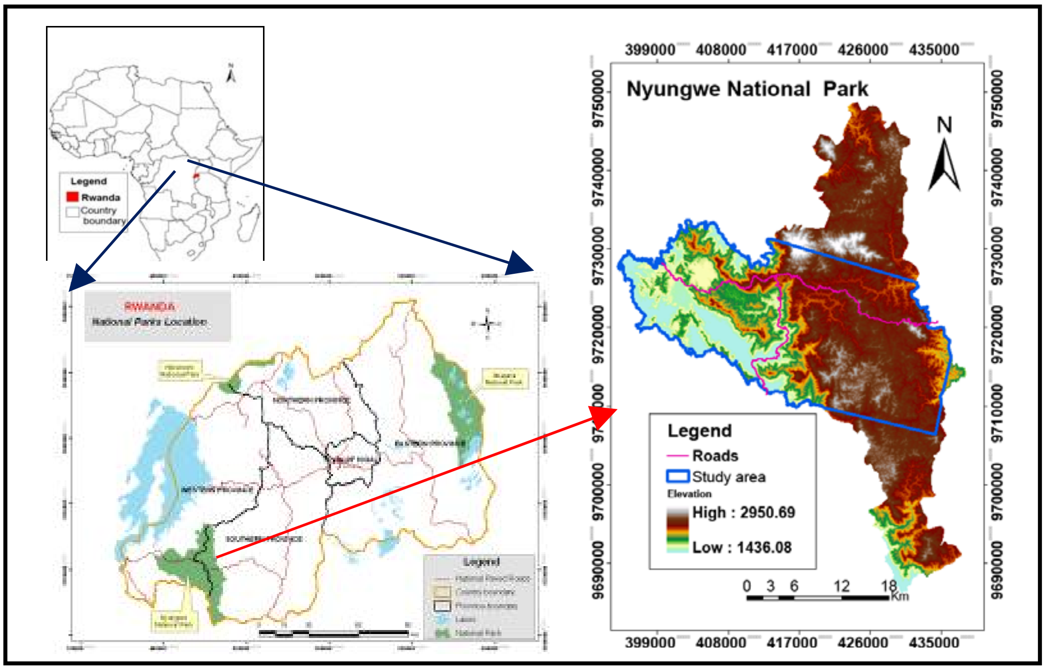

Figure 1: Location of study area

Nyungwe shelters nearly 70% of the country's waters and supports an abundance of wildlife. Rainfall feeds into two watersheds, the Congo and Nile Basins, while its forest protects the source of the Nile river, ensuring critical water supplies for downstream users in neighbouring countries as far away as Egypt. 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 Albertine Rift (Dowsett 1990). This 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 Albertine Rift (Plumptre, Masozera et al. 2002). Thirteen species of primates are known to inhabit the forest.

2.2. Data collection and generation

Topographic maps and vector data including the road network, elevation contours and park boundary were obtained for the study area. This data were pre-processed and then imported into a ArcGIS desktop and a mobile GIS (ArcPad) platform for use in field surveys.

Fieldwork was conducted between September and October 2007. A perpendicular transect to the road was accessed horizontally and vertically within each of seven samples points in a 100m transect. Besides presence/absence records of epiphytes, several environmental parameters were collected. The sampling of epiphyte species was done as follows: (1) Collecting fallen branches, very often due to the age of the host tree and wind influence. (2) Wood poles were used to get specimen of epiphytes up to an approximated height of 15m. (3) Binoculars for well developed epiphytes in high canopies and (4) Climbing exercises were also used for observations and/or specimen collection in mid and top branches of tall trees.

The following additional information was recorded for each sample point: X, Y coordinates and elevation using a GPS Garmin 12 receiver, slope gradient and slope aspect using clinometers and compass.

For modeling vascular epiphyte, we used elevation, slope, aspect and terrain shape index. This method of modeling has been successfully used in previous studies, where topographic attributes derived from a Digital Elevation Model (DEM) were used as explanatory variables for the prediction of plant species distribution in mountainous areas (Lassueur, Joost et al. 2006; Zhao, Nan et al. 2006).

2.2.1. The Digital Elevation Model (DEM) was generated from the elevation contour lines of 25m equidistance created by digitizing a scanned, geo-referenced and geo-coded topographic map sheets of the scale 1:50,000 dating from 1988. These contours were rasterized using a common grid (15x15m) and the DEM from the contour data was created. The quality of the DEM was improved by taking into account the features that are not shown by the contours such as ridges and valley bottoms. The sinks were also filled.

2.2.2. The Slope gradient map was necessary for distance weighting in the road edge impact delineation. The slope map was derived from the digital elevation model.

2.2.3. Terrain shape index (TSI)

The terrain shape index represents the average 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. The following equation using a window of 5 x 5 pixels was proposed (McNab 1989):

TSI = dem - focalmean (dem, circle, 5)

The above equation has been implemented in the ArcGIS/Spatial Analyst tools and the raster calculation for generating the terrain shape index map. From the generated TSI map, pixel based values have been extracted using the Spatial Analyst tool - zonal statistics of ArcGIS. This was used as a variable in further statistical model analysis.

2.3. Data analysis

The predictors choice is a major concern for building any predictive model (Hessami, Gachon et al. 2007; Lang, Nilson et al. 2007). Prior to train the model, the variables were screened. The data set was too small to be split into training and test data sets. Thus, the screening was done based on all data set (N = 161). 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 the variables data were 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.

In this study, a GLM- stepwise logistic regression fits our data well for prediction of vascular epiphyte biodiversity, on the basis of continuous and/or categorical independent variables. The results of a logistic regression can be assessed by looking at the correct and the 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, the area under the ROC (Receiver Operating Characteristics) curve and the Akaike's information criterion (AIC) were calculated.

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 have been multiplied with its coefficient. For visualization, the resulting maps of impact gradient and probability level were classified in four different classes.

3. Results

3.1. Predictor variables

A stepwise logistic regression was carried out of the vascular epiphyte presence/absence with canopy cover density, canopy thickness or height, emergent height, emergent cover, trees height, trees cover, understorey height, understorey cover, elevation, light intensity, slope, aspect and terrain shape index.

3.2. Spatial prediction of vascular epiphyte probability to occur

The backward stepwise elimination model predicted vascular epiphyte distribution with 5 explanatory variables namely terrain shade index (**-0.60**), tree height (0.085), canopy density (0.074), emergent cover (0.077) and elevation (-0.003). Table 2 shows that there is a highly significant negative relationship between vascular epiphytes and the **elevation** and the **terrain shape index.**

Table2: Summary of Logistic regression model

Variable	**Coeff.**	**Std Error**	**Pr (>/z/)**
Constant	1.135	2.530	0.654
Elevation	0.003	0,001	0.006
Canopy density	0.074	.023	0.000
Trees height	0.085	0.033	0.011
Emergent cover	0.077	0.025	0.002
TSI	**- 0.60**	0.211	0.006

Canopy density, canopy height and emergent cover were variables significantly contributing to the above regression model. It was not however, included in the spatial prediction of vascular epiphyte probability to occur because it was difficult to map the spatial distribution of those factors. Only the elevation (DEM) and the terrain shape index were easier to map (see Table 3 and Figure 2). Hence, we used the elevation and the TSI in the best fitting model using these variables, which explained 77.6 % of the probability of vascular epiphyte to occur.

Table3: Summary of Logistic regression model for spatial pattern visualisation

Variable	**Coeff.**	**Std Error**	**Pr (>/z/)**
Constant	7.910	1.809	0.000
Elevation	0.003	0,001	0.006
TSI	**- 0.242**	1.106	0.023

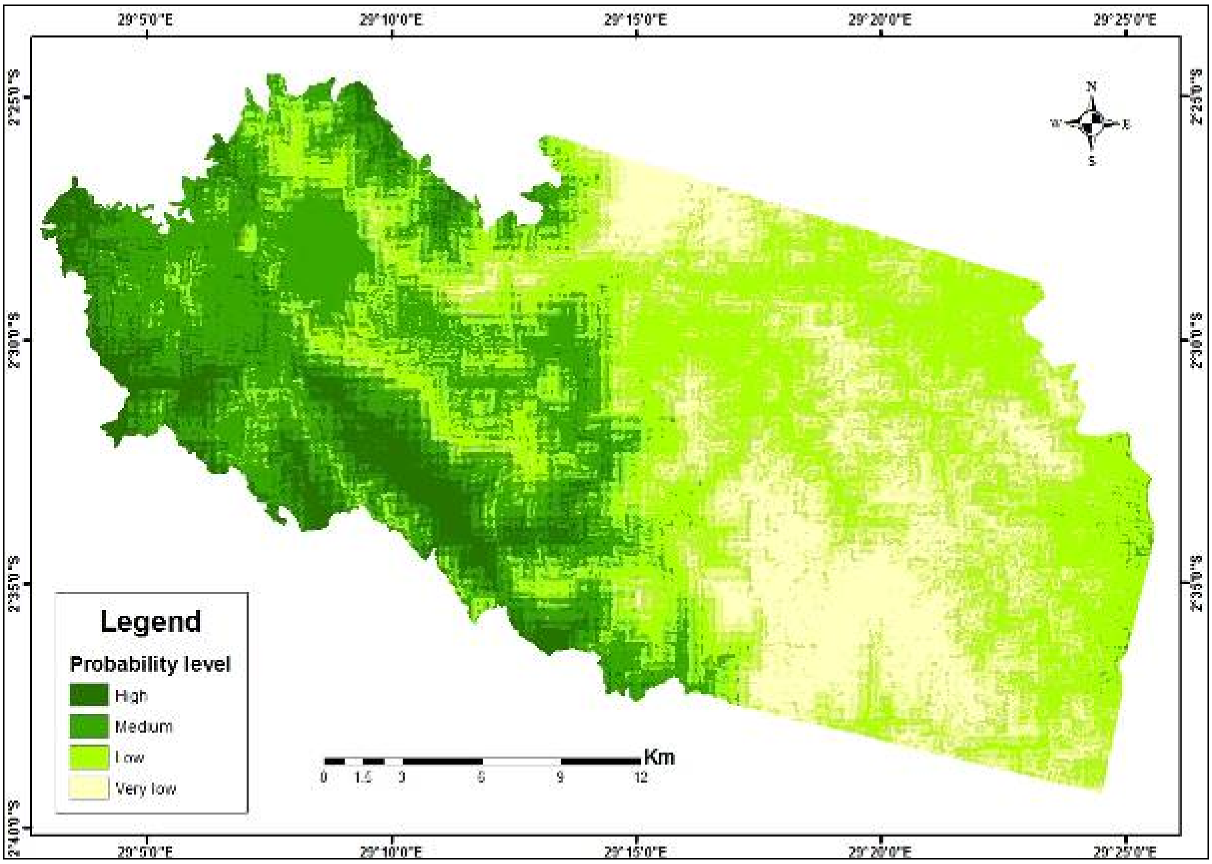

Figure 2 Probability of vascular epiphyte to occur in relation with landform (Terrain shape index and elevation)

4. Discussion

The terrain shape index offers important information for distinguishing the implications of changes in vegetation and climate, because elevation and exposition rather than soil types determine communities and site suitability in mountainous areas (Fontaine, Aerts et al. 2007). These variations explain the negative relationships between vascular epiphyte presence/absence and terrain characteristics. The limited available literature suggests 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) Mucunguzi (2007) found that beyond 2500 meters vascular epiphyte was very rare.

The relationships between vascular epiphyte presence/absence and environmental variables are non-linear and the GLM provided effective ways in detecting these relationships. This study reveals strong relationships between vascular epiphyte occurrence and the terrain shape index.

Acknowledgements

I would like to express my sincere thanks to the institutions and individuals, who have played an important role in the work required to complete this study. First, the Government of the Netherlands through the Netherlands Programme for the Institutional Strengthening of Post-graduate and Training Capacity (NPT), for providing the financial support to pursue a higher education programme in the Netherlands. To the National University of Rwanda (my employer) for providing me the opportunity to pursue studies. We thank the Rwandan government and the Rwandan Office for Tourism and National Parks (ORTPN) for permission to conduct the study in Nyungwe National Park.

Useful comments and support for this work was received from Mr. Andre Kooiman, Prof. Jan de Leeuw of ITC/The Netherlands, Prof. Kurt Brussel, Dr Felicia Akinyemi, Martina Foster and Tim Wolff.

References

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

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

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.

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

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**.

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.

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

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**.

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.

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

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**.

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."

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.