

Modelling tree species diversities of the Afromontane forest ecosystem with Satellite Remote Sensing and Macro-ecological data.



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Abstract

The research examines the application of Spectral Variation Hypothesis (SVA) in an Afromontane forest ecosystem using features derived from high and medium resolution images combined with macro-ecological data to predict tree species distribution. Alpha diversity (α) of tree species were calculated from in situ data obtained from survey of two study sites. The Object Based Image Analysis (OBIA) was adopted for the tree species distribution modelling. Spectral and textural metrics from the both QuickBird and Landsat images were computed with the segmentation algorithm. While the macro ecological parameters (temperature, humidity, elevation and slope) were derived from 30 m ASTER DEM and CHELSA high resolution climatic data. The relationships between diversity and spectral, textural features derived from the two images and the macro-ecological parameters were assessed with random forest algorithm. Elevation ($r=0.55$), and slope ($r=0.46$) were the determinant of tree species distribution in the study area. While spectral and textural features significantly contributed to the enhancement of the alpha diversity model in both QuickBird and Landsat images. QuickBird and Landsat ETM-8 spectral and textural heterogeneity showed a significant correlation with species richness ($r=0.78$) and ($r=0.47$) respectively. The empirical models developed can be used to predict landscape-level species density in the Afromontane forests of Nigeria and the adjoining Cameroon highlands.

Key word: Afromontane, Ecosystem, Tree species, Modelling, Satellite images, Macro-ecological

Introduction

Montane forests situated in the afro tropical region (henceforth referred to as “Afromontane forests”) are on the list of the world’s most threatened ecosystem. These ecosystems are highly diverse and adjudged as repositories of genetic diversities. Information on the biodiversity of such an important area is a prerequisite for effective conservation and management strategy (Hernández-Stefanoni, Gallardo-Cruz et al. 2012). Ecologists have relied on the traditional method of field survey to quantify biodiversity of large area, which often is time consuming, costly and dependent on expert knowledge (Palmer et al. 2002, Hernández, et al. 2012). This has led to the conclusion that field measurements represent estimates rather than absolutes. Information on landscape biodiversity can be optimized through use of ecological proxies (Palmer et al. 2002). Plant species richness is widely adopted as an ecological proxies for the determination of biodiversity and is often correlated with diversity at other levels of organization, such as genetic diversity and ecosystem functioning (Boyd et al. 2016). Plant species constitutes the primary components of terrestrial ecosystem and can be used as a surrogate for ecosystem biological diversity.

Thus, plant/ species richness defines ecosystem structures and functions, and is therefore a central component of biodiversity assessment (Chiarucci et al. 2004).

Species diversities do not occur in isolation, rather diversities can be directly linked with their environment or habitat heterogeneity. Habitat heterogeneity is a determinant of species diversities both at local, regional and global scales (Warren, Alt et al. 2014). Ecologist have subscribed to the theory of the existence of a linear relationship between diversity and environmental gradients. Afromontane forests are located across broad range of landscapes with various abiotic factors influencing plant diversities and productivities (Antonio Vazquez and Givnish. 1998). For instance, macro-ecological factors such as slope, elevation, aspects and solar radiation are known to affect the distribution of insolation in the terrain (Gallardo-Cruz, Pérez-García et al. 2009). Theses also have effects on the ecosystem microclimate (soil moisture and nutrients), thereby impacting resource gradients for plants.

Understanding the relationship between species richness and habitat heterogeneity is therefore crucial to habitat conservation (Jennifer.K, Aaron. et al. 2011). A new frontier of obtaining information on biological diversity at using remote sensing is the

application of the Spectral Variation Hypothesis (SVH) proposed by Palmer (Palmer, Michael W, Earls, Peter G et al. 2002). SVH infers that the spectral heterogeneity of a remotely sensed image can be correlated with habitat heterogeneity (Wesuls et al. 2010). Therefore SVH represents a potential tool for predicting plant species diversities at local, regional and global scales with satellite remote sensing (Ricotta et al. 2007). Optical satellite images provide the bulk of satellite images used in the application of Spectral Variation Hypothesis for modelling species diversities. The debate on the efficiency of high and medium resolution images for modelling species diversities has been ongoing for a sometimes. High resolution sensors have greater potentials for mapping vegetation diversity and distributions owing to the pixel sizes which correspond with individual tree crowns. The major demerit of high-resolution data sets for tree species mapping is the potential for increase in pixel variability. This is often the case in mountainous region, where a pixel may cover crown area with sunshine and shadow at the same time. The Spectral Variation Hypothesis has been fully tested on vascular plants using high resolution images such as Ikonos and QuickBird (Rocchini 2007, Ricotta et al. 2007, Nagendra and Rocchini 2008, Immitzer, Atzberger et al. 2012, Warren, Alt et al. 2014).

The medium resolution images such as Landsat have greater number of bands and are able to record additional information in the middle infra-red range of critical plant properties including leaf pigments, water content and chemical composition and can be useful for discriminating tree species (Nagendra, Rocchini et al. 2010). The major limitation of the medium resolution sensors has been that of insufficient spatial resolution. A single pixel of the medium sensor may cover a number of plant of different species, thus each pixel often correspond to mixed signature of different objects, leading to difficulties in species identifications (Nagendra, Rocchini et al. 2010). Despite these limitations, studies using the medium resolution sensors have been moderately successful for both temperate and tropical ecosystem (Hernández-Stefanoni, Gallardo-Cruz et al. 2012, Higgins, Asner et al. 2012).

Majority of research on species/ spectral diversity modelling with satellite remote sensing has been dedicated to the relationship between spectral entropy and local species diversity (He, Bradley et al. 2015). Analysis of habitat and spectral heterogeneity for species diversity studies requires an analytical technique with information beyond the spectral variability of both the high and medium resolution images. A recent approach to Spectral Variation Hypothesis is now focused on the use of textural variables and vegetation indices computed with the object based image analysis technique (Kessler 2002). This

method has the dual advantages of the use of both spectral and textural features to discriminate and determine species diversity. Also in object based image analysis, field plot is linked to an object rather than a pixel hence the geometric inaccuracies in both field and image data are of less importance (Elisabeth A. Addick, Steven m. de Jong et al. 2007). The object features often related with SVA is the second order statistics after Haralick (Haralick 1979, Haralick and Shapiro 1991).

The second-order statistics is the Gray Level Concurrence Matrix (GLCM). The Gray Level Co-occurrence matrix (GLCM) is the second order texture features after Haralick (Haralick 1979). GLCM features provide information on the structural and geometric properties of forest canopies and can be used to discriminate textures between tree species (Ouma, Y. O and T. 2006). There are arrays of literatures suggesting the advantages of the object-based image analysis over the pixel-based analysis in land cover classifications (Desclée, B, de Wasseige, C et al. 2006, Abbas S, Qamer F. M et al. 2010, Chen, Hay et al. 2012, Chen, Hay et al. 2012); biomass estimations (Fuchs, Magdon et al. 2009, Kajisa, Murakami et al. 2009, Katharine, C. Kelsey and Neff 2014); and species diversity/ecological modelling (Addink, de Jong et al. 2007, Immitzer, Atzberger et al. 2012, Viedma, Torres et al. 2012). Satellite remote sensing has been used for mapping and modelling species distribution in arrays of ecosystems ranging from temperate {Nagendra, 2008 #405} (Palmer, Michael W, Earls, Peter G et al. 2002, Rocchini, Chiarucci et al. 2004, Rocchini 2007, Rocchini, Ricotta et al. 2007) and tropical (Hernández-Stefanoni and Dupuy 2007, Hernández-Stefanoni, Gallardo-Cruz et al. 2012), but none of the studies has focus on the subtropical Afromontane ecosystem.

This research is aimed at modelling the structural diversity of the Afromontane forest ecosystem using high resolution QuickBird and medium resolution Landsat 8 satellite images combined with macro-ecological data. The objectives of this study are to: 1) Determine the relationship between sensor spatial/spectral resolution and species diversity using high resolution QuickBird and medium resolution Landsat 8 images. 2) Determine the relationship between species richness and satellite image spectral, textural and vegetation indices, and, 3) determine the effects of macro-ecological parameters on the Afromontane tree species diversity.

Study area

The study was carried out in the highlands of North East Nigeria, along the Nigerian/Cameroon border (Fig 1). These highlands are part of the Cameroon volcanic chain of mountains ranging

from mount Oku in the north of Cameroon to Bioko in the south. These highlands are primarily grassland with patches of forest restricted to slopes where they are protected from fire and grazing or along stream sides where there is moisture and again some protection from fire (Chapman. J. D and Chapman.H.M. 2001, Chapman, Olson et al. 2004). The study concentrated on two main areas, the Ngel Nyaki forest (Longitude 07° 20' N and Latitude 11° 43' E) and the Kurmin Ndanko (Longitude 07° 03' N and Latitude 11° 70' E). The altitude of the study sites varied from 1250 m to 1750 m above sea level.

The forests are representative of sub montane moist broadleaf (Terrestrial Ecoregion, WWF) and are highly diverse in both fauna and flora (Dunn 1993). Afromontane endemic tree species

(White 1981), Cameroon highland endemics and possible local endemics are found in the forests of the study area. The forests are also rich in mammal species, especially primates including the Nigerian-Cameroon Chimpanzee (*Pan troglodytes ellioti*), noted as the most endangered subspecies of chimpanzee in Africa (John, Richard et al. 2004). There are two distinct seasons, a dry season when there is little or no rain of approximately 6 months and a wet season when it can rain almost every day. The rainy season usually commences from early April until late October (Sumarga, Hein et al. 2015) with mean annual rainfall of 1780 mm in the Ngel Nyaki and Kurmin Ndanko. The temperature of the study area rarely exceeds 30°C (Sumarga, Hein et al. 2015).

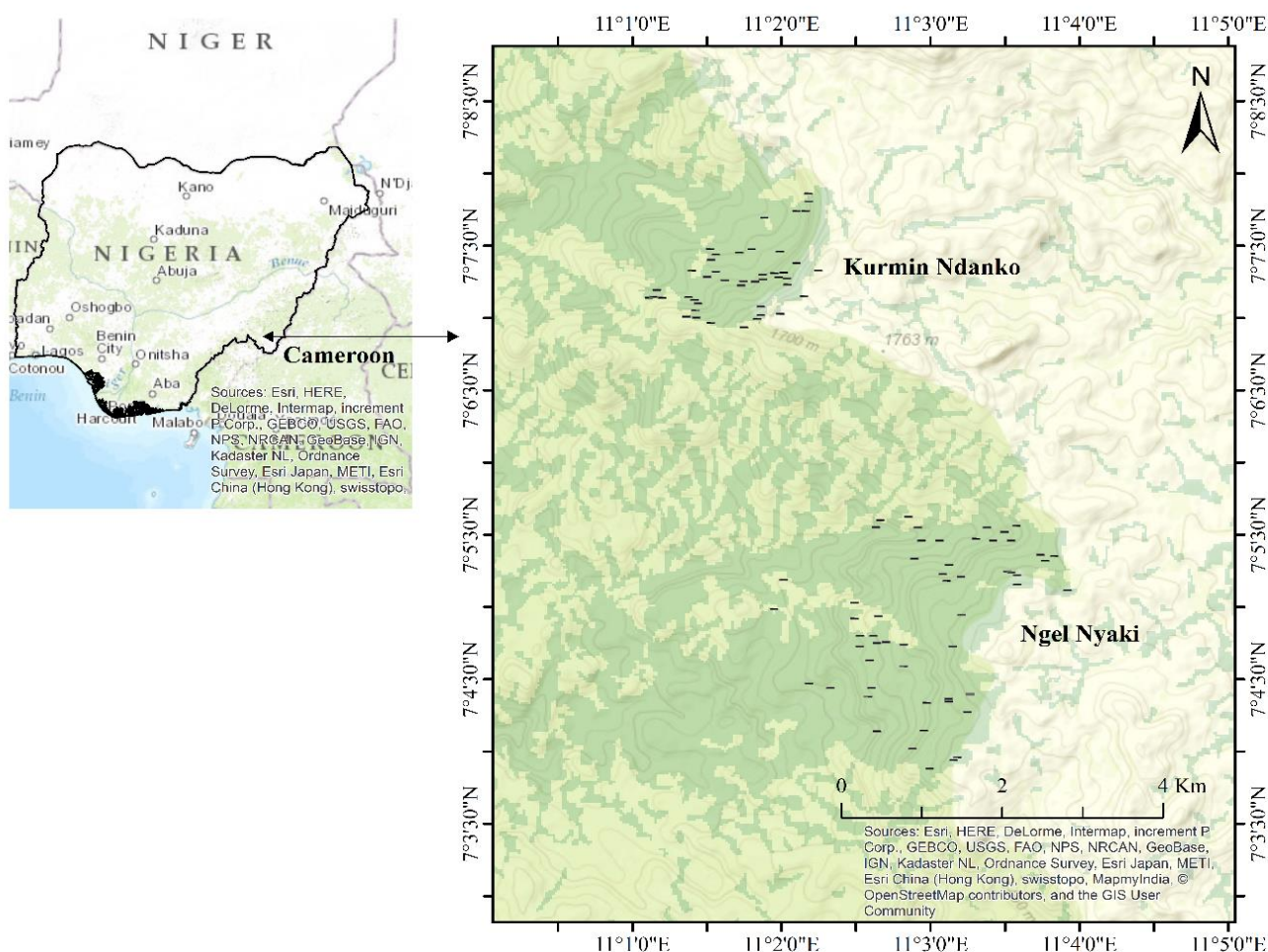


Figure 1. Showing plot layout along macro-ecological gradients in Ngel Nyaki and Kurmi Ndanko forest.

Materials and methods

The approach described below aim to determine tree species richness using features from QuickBird and Landsat 8 satellite images (textural, spectral and vegetation indices). Also included as explanatory variables were slope, elevation, annual solar irradiance, temperature and annual precipitation). All the procedures are described in details with figure 4-8.

Plot inventory/ alpha diversity study

Afromontane tree species inventory data were collected using the modified Gentry plots (Baraloto, Rabaud et al. 2011). Plots were established using randomized co-ordinates stratified by elevation (1250 m– 1750 m above sea level). Within the modified Gentry plots, all living trees with diameter at breast height (dbh) ≥ 10 cm were identified and recorded using Trees of Nigeria (Nielsen 1991), The Forests of Taraba and Adamawa States, Nigeria-An Ecological Accounts and Species Checklist (Chapman. J. D and Chapman.H.M. 2001) and local knowledge of the trees. A total of One hundred and six plots were established in the two sites. Tree species richness by plot were assessed with the Simpson's diversity indices as a measure of alpha (α) diversity index (Seaby 2006, Saiful 2008).

Satellite images and macro-ecological data acquisition and processing

QuickBird satellite image of the study area was acquired at the onset of the field campaign in January, while Landsat 8 (OLI) satellite images was acquired in March 2020. Both images were atmospherically corrected and geo-referenced to Universal Transverse Mercator Projection (WGS 84). Elevation, slope and solar radiation study area were extracted from the 30m ASTER Global Digital Elevation Model of the using the Spatial Analyst and Topography toolbox in ArcGIS 10.2.2. Precipitation and temperature data were obtained from the CHELSA- World Data Centre for Climate (Hijmans, Cameron et al. 2005).

Within each of the 106 plots, the alpha diversity (species richness), the mean spectral bands of Quick Bird and Landsat 8, slope based vegetation indices, textural features consisting of the Gray Level Co-occurrence matrix (GLCM) and macro-ecological features (Elevation, slope, Mean Solar radiation/annum, temperature and precipitation) were extracted using the chessboard segmentation algorithm in the Trimble Developer software (eCognition 9.0.3).

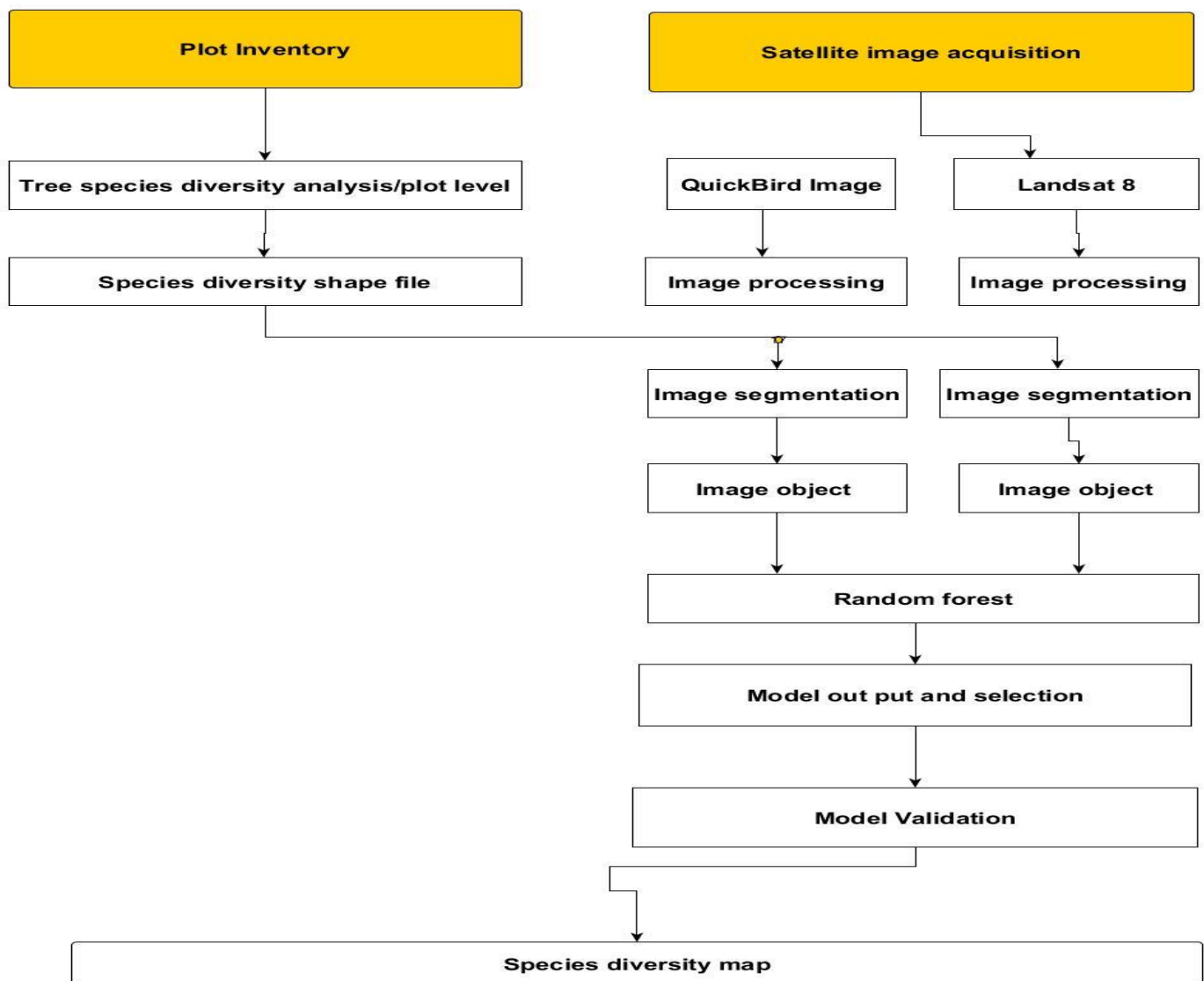


Figure 2. Diagrammatic scheme of methods and process for species diversity study

The GLCM properties used are as follows; homogeneity, contrast, dissimilarity, entropy, angular second moment, mean, standard deviation, and correlation. All of the textures measured were computed for each layer and for the five different directions; namely 0°, 45°, 90°, 135°, and all directions. The afore-mentioned features and thematic layers with information containing specie richness were exported as a shape file from the eCognition environment and used in the random forest algorithm to model Afromontane tree species richness.

The relationship between spectral, textural and vegetation indices of Quick Bird and Landsat 8 satellite images and species diversity (≥ 10 cm diameter at breast height) were explored using multiple regressing analysis with the random forest algorithm. An independent data set was used to test the predicted model using linear regression. In other to explore the relationship between tree species diversity and spectral, textural and vegetation indices and. Pearson correlation coefficient were computed as a measure of relationship. The closer the coefficient is to one, the stronger the relationship.

Results

The model output from random forest algorithm was validate and evaluated with the coefficient of determination. The coefficient of determination derived from validating modelled species heterogeneity and field-based species richness was statistically significant for Quick Bird, $r^2=0.77$ and Landsat 8, $r^2=0.47$. (Figure 3 & 4). Correlation coefficient for the relationship between species diversity image features (spectral, textural and vegetation indices) and macro- ecological features ranged between 0.1 and 0.8 (Table 1 & 2).

Table 1. Correlation coefficient between tree species diversity and macro ecological variables

Macro-ecological features	R
elevation	0.55
slope	0.46
temperature	0.12
precipitation	0.13

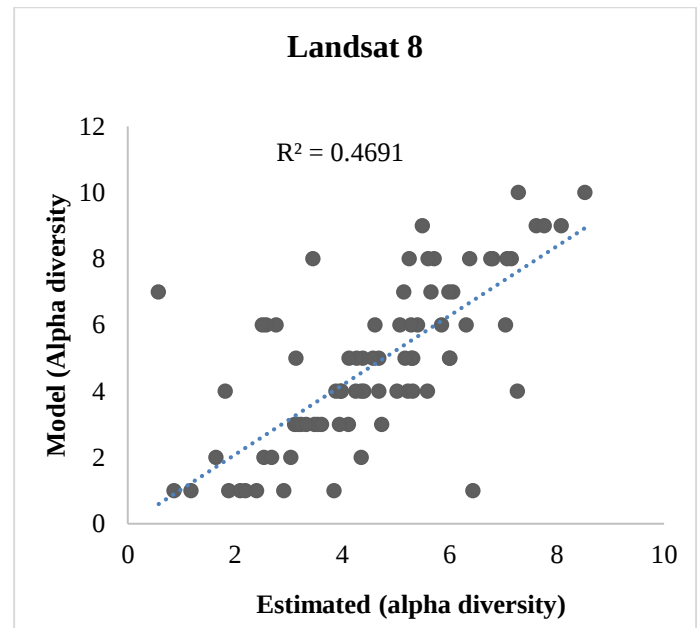


Figure 3. Landsat 8 species distribution model

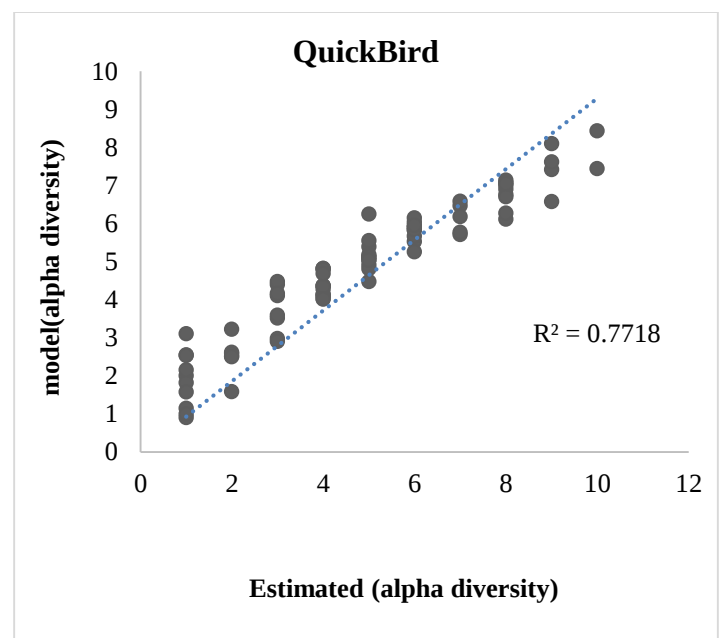


Figure 4. Quick Bird species distribution model

Table 2. Correlation coefficient between spectral bands, vegetation indices, texture and species richness

	Landsat	QuickBird
Spectral Bands		
Blue	0.3	0.5
Green	0.2	0.1
Red	0.5	0.3
NIR	0.41	0.52
Vegetation Indices		
DVI	0.04	0.13
GDVI	0.32	0.11
GNDVI	0.3	0.20
NDVI	0.1	0.30
NG	0.31	0.13
NNIR	0.04	0.23
RVI	0.1	0.25
GRVI	0.28	0.16
NR	0.20	0.31
Texture		
GLCM	0.3	0.45

Discussions

Both QuickBird and Landsat 8 satellite images correlates with species richness of the Afromontane forest ecosystem. The species heterogeneity maps showed pattern of tree distributions in the study area with the lowest heterogeneity range of 0, belonging to the grass and ≥ 1 to ≥ 10 belonging to ecosystem ranging from savanna to high forest ecosystem (Figures 4-5 and Figures 4-6). The QuickBird satellite image (with a spatial resolution of 2.4 m) showed propensity for distinctive mapping of individual objects due to its high spatial resolution as opposed to Landsat 8 which had a medium (30 meter) spatial resolution. High resolution images such as used in this study are potentially suited for tree species diversity mapping owing to

the suitability of the pixel size corresponding to tree individual tree crowns (Rocchini, et al. 2007).

The NIR band of the two-satellite image correlated with species diversity. The Near Infra-red band (NIR) is generally known to correlates with vegetation and is adjudged to be the most important spectral band for mapping and modelling vegetation properties (Rocchini, Balkenhol et al. 2010). Similar studies on the use of spectral heterogeneity to determine species diversity corroborated these finding. For instance, a study using QuickBird spectral heterogeneity found that the NIR band was linearly related to species richness ($r=0.48$) (Rocchini, Ricotta et al. 2007). The slope based vegetation indices are widely used as an indicator of green vegetation and biomass abundance (Silleos, Alexandridis et al. 2006). The NDVI of both satellite image strongly correlated with species diversity.

It has been observed that using spectral and texture information as a proxy for estimating species diversity without including additional multiscale drivers such as climate, topography and other abiotic interactions may lead to inaccuracy (Rocchini, et al. 2016). Two of the three macro ecological factors strongly correlated with tree species diversity (slope, and altitude). Slope of the terrain and the direction which it faces has been observed to have multiple effects on montane species diversities (Marshall, Willcock et al., Daniels and Veblen 2003). These factors have been found to have linear relationship with vegetation attributes such as species richness and diversities (Lomolino 2001). Species distributions and richness pattern are also known to be regulated by altitude, slope and aspects (Sharma, Suyal et al. 2009). A similar field survey confirmed that area with high escarpment in and around the forest core were rich in tree species. Similar to that was the observation of decrease in tree species richness along altitudinal gradients. Plant species diversities have been observed to decreases with increasing elevation in tropical montane forests (Gentry 1988, Kessler 2002, Homeier, Breckle et al. 2010).

Figure 4. Alpha diversity map of Ngel Nyaki montane forest from QuickBird (left) and Landsat 8(right).

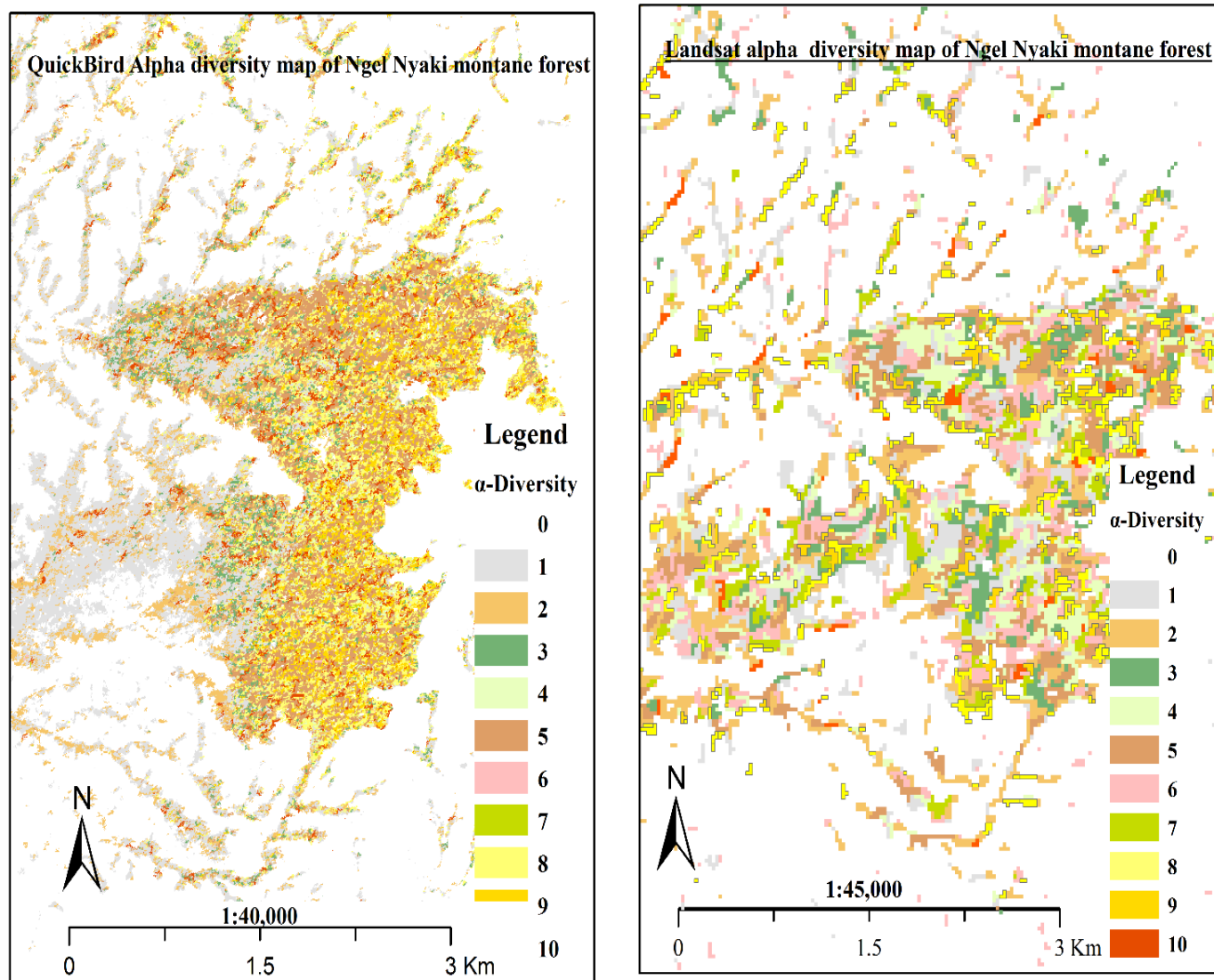


Figure 4. Alpha diversity map of Ngel Nyaki montane forest from QuickBird (left) and Landsat 8(right).

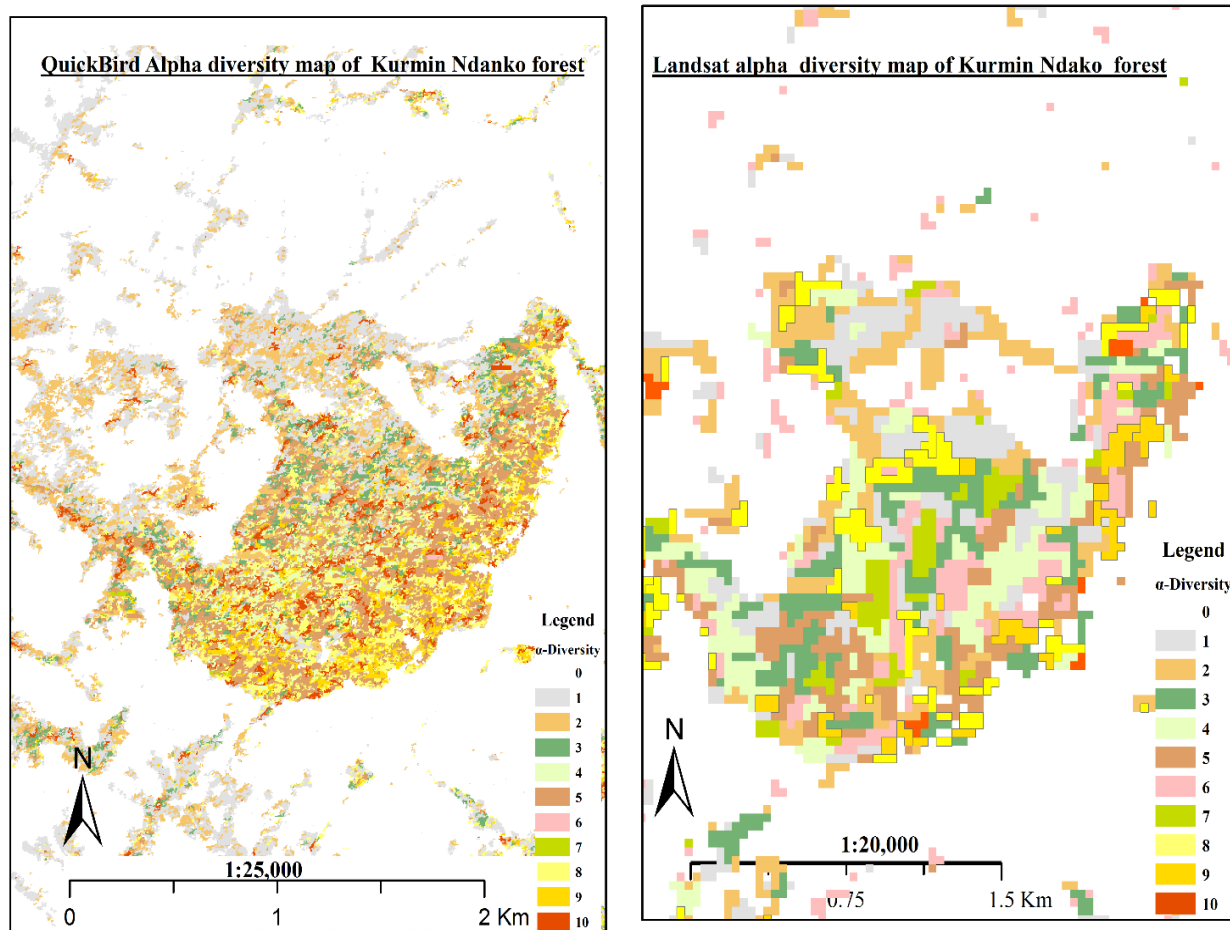


Figure 5. Alpha diversity map of Kurmi Ndanko montane forest from QuickBird (left) and Landsat 8 (right)

Heterogeneous landscapes such as the study area are reservoir genetic diversities due to the complex interaction of the various micro and the macro ecological factors. Aspects and slope are relevant to the existence of high tree diversity in the study area. Dense canopy and high tree species diversities were restricted to areas with high slope and escarpment. While Savannah and grassland of the study areas are in locations with low escarpments as shown in the map. This is an indication of current anthropogenic activities in the area. Anthropogenic activities occasioned by forest fires are limited to flat land and drier land surfaces, while the steep slope occasioned by wet soils and close canopies restricted the entry of fire into the forest.

The importance of remote sensing in tropical species diversity mapping has been emphasized through numerous researches and has often been limited to the use of the spectral band and vegetation indices for tree species discrimination and mapping. However, the advantages of tree species mapping through the

pixel segmentation combined with satellite image spectral features and vegetation indices in object-based image analysis is being deduced herein. In mountainous vegetation, the possibility of hill side shadow covering a forest area is well known and documented. The image segmentation algorithm played a significant role in canopy cover mapping, discrimination of forest covered by shadow by adjoining hills from other Eco zones.

Remote sensing has the potential of shaping the next generation of species distribution model when fully exploited with biotic and abiotic variables (He, et al. 2015). The theoretical approach of this model is that species richness can be spatially represented in biodiversity hotspots. The inclusion of macro ecological parameters with satellite remote sensing for modelling Afromontane tree species diversity is an indication of the importance of the macro ecological variables in the species distribution of the study area. Species distribution modelling can be used as habitat mapping for endemic species

such as the Nigerian-Cameroon Chimpanzee (*Pan troglodytes ellioti*) and other species known to be present in the two study sites. However, it worth noting that remote sensing still has the limitation of mapping individual tree species especially in a tropical ecosystem with layers of species within a few meters.

Conclusion.

Plant species richness is often used as an indicator of ecosystem diversity and health (Warren, Alt et al. 2014). The study has demonstrated the use of remote sensing spectral and textural heterogeneity for the spatial modelling of Afromontane hotspots. Both QuickBird and Landsat 8 images positively correlated with tree species diversity. However, detailed object features were captured by the higher resolution image than the medium resolution. The medium resolution image had mixed pixel effects and hence was less sensitive to spatial the complexity (Rocchini 2007) of the Afromontane forest ecosystem. The combination of textural and spectral features of both satellite images improved the ability of the images to discriminate and predict tree species richness. The study also revealed the influence of macro-ecological data on the Afromontane tree species distribution. The empirical models developed can be used to predict landscape-level species heterogeneity in the Afromontane forest of Nigeria and the adjoining Cameroon highland.

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