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Research Article

Climatic and soil integrant that drive forest tree species diversity and distribution across cross-river state, Nigeria

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Abstract

Awareness of the ecological needs of forest tree species is a necessity for effective and tenable forest management, conservation and restoration. Our study used the modified Whittaker sampling method to assess the diversity and distribution of forest tree species at twenty-two forest sites across northern, central, and southern Cross River State, Nigeria, and to analyse climatic and soil integrant that drive the diversity and distribution of tree species in forests. Only tree species with dbh $\geq$ 30 cm were identified and recorded. Tree species occurrence points were also marked using Global Positioning System (GPS) software. Maximum Entropy (MaxEnt) species distribution model and principal component analysis (PCA) for each zone were used to study climate and soil integrant that drive forest tree species diversity and distribution, respectively. The results of the survey revealed a great diversity of tree species in the forests, as 398 species belonging to 64 families were recorded. The maxEnt model established six climatic integrants that drive forest tree species diversity and distribution across Cross River State. These are ‘BIO 3 – isothermality’, ‘BIO 4 - temperature seasonality’, ‘BIO 7 - annual temperature range’, ‘BIO 12 - annual precipitation’, ‘BIO 16 - precipitation of wettest quarter’, and BIO 17 - precipitation of driest quarter. PCA revealed that the soil in the northern zone had seven main integrants (iron, Available Phosphorus, manganese, exchangeable cations, silicon, Hydrogen ion and organic matter); ten in the central zone (zinc, organic matter, iron, Total Nitrogen, Sodium, boron, clay, soil pH, exchangeable acids and silicon); and nine in the southern zone (sand, silt, Organic Carbon, Manganese, Hydrogen ion, Calcium, cation exchangeable capacity, Potassium and clay) that drive species diversity and distribution. Our findings can be used as rudimentary details for managing forest and ecosystem preservation at all levels and, characteristically, for forest conservation across Cross River State, Nigeria.

Keywords: Forest ecosystem**,** Ecological conditions, MaxEnt model, Principal component analysis

Introduction

Cross River State is a coastline state situated in Southern Nigeria and termed after the Cross River, that runs across the state. The land area of the State is approximately 20,156 square kilometres. The State lies between, latitude 5° 45′N and 6˚ 10ˈN and on longitude 8° 30′E and 8˚ 39ˈE (Aju & Ezeibekwe, 2010). Cross River State belong to a tropical rainfall belt in which rainfall is customarily periodic and at times exceptionally dense. The humid tropical climate of about 1300 – 3000 mm rainfall and 30˚C mean annual temperatures prevail over Cross River State, excluding on the Obudu Plateau, in which the climate is semi-temperate, with temperatures of 15 – 23˚C (NIMET, 2015). The flora spans from mangrove swamps, across rainforest, to derived savannah, and montane parkland. The state is further divided into three regions namely; north, central and south. Each region is further distinguished by its own distinctive environmental and soil features (NIMET, 2015). Currently, the state has more or less 31% of the entire existing tropical high forests in Nigeria (Philip *et al.,* 2014).

The tropical rainforests are the greatest bio-diverse of all earthly ecosystems (Turner 2001; Onyekwelu *et al.,* 2008; Schmitt *et al.,* 2009; FAO, 2010; IUCN, 2010). Despite accounting for at most 7% of the terrestrial parched exterior area, rainforests sustain about 70% of all animal and plant species in worldwide ecosystems (Lovejoy, 1997). Around 100 and 300 tree species ha^{-1} are located in rainforests (Onyekwelu *et al.,* 2008). Forests play a critical function in supporting foundational ecological processes, in addition to equipping livelihoods and upholding economic growth (UNEP, 2007; FAO 2009). Trees species are vital constituents of the forest ecosystems. According to Singh (2002), trees in addition to solidifying the crucial structural and practical foundation of tropical rainforest, are essential as carbon sinks, water sheds, make available shades and homes for several life forms and most importantly serve as a main harvester of energy into the ecosystem. Trees diversity is vital to tropical forest biodiversity, since trees make available homes and resources to a wide array of plant and animal species. For that reason, they control the design and affect the make-up of forest communities. The size, amount or degree of the biodiversity of an ecosystem impacts the total health standing of the ecosystem (Naidu &

Kumar, 2016). The firmness or permanence and task of the ecosystem are controlled by the variation of vegetation (Buba, 2015). There is also burgeoning proof on the good effect of elevated species variation in physical surrounding work like controlling the gradual wearing away of land surface materials by the action of water, winds, waves etc. (Ogunjemite, 2015).

Generally, the diversity and distribution of tree species in forest ecosystems is multiplex as it requires a host of direct integrants such as climate and soil. Tree species rely upon the usage of water, a substance that provides essential food for sustaining life and growth and light as key assets for growth. In tropical rainforests, these assets differ along topological and geographic scales, and because of this, tree growth differs with asset availability. Climatic features like atmospheric pressure, temperature, rainfall, sun energy and so on can facilitate the dispersion of species as well as lead to the extinction of endangered species (Körner 2007; Diem *et al.,* 2018). Furthermore, Climate components like temperature and precipitation over time have been proven as major determinants of the diversity of tree species and distribution in forest ecosystems at temporal and spatial scales (Hall & Swaine, 1976; Murphy & Lugo, 1986; Swaine, 1996; Bongers *et al.,* 1999; Lu *et al.,* 2002; Malhi *et al.,* 2004; Russo *et al.,* 2005; ter Steege *et al.,* 2006; Engelbrecht *et al.,* 2007; Baltzer *et al.,* 2008; Toledo *et al.,* 2012; Condit *et al.,* 2013; Diem *et al.,* 2018; Sirlluck *et al.,* 2021). Also, physical and chemical soil attributes such as physical texture, soil moisture, nutrients and acidity levels have been established to influence vegetation arrangements in a particular area or local scale (Aranguren *et al.,* 1982; Oliveira-Filho *et al.,* 1998; Hejcmanovā-Nežerková and Hejcman 2006; Han *et al.,* 2011; Toledo *et al.,* 2012; Zhang *et al.,* 2013; Sarker *et al.,* 2014; Zhao *et al.,* 2015; Zhang *et al.,* 2016; Tilk *et al.,* 2017).

Climatic and soil factors affecting vegetation patterns may vary by region or terrain. Accordingly, it is necessary to establish such fundamentals. This will make available ecological data imperative for satisfactory and efficient management of forests and forest assets. Cross River State lacks insight into the climate and soil integrants that drive the diversity of forest tree species and their distribution among forest ecosystems. There is no available literature or published work in this area. Hence, our study bridges this gap. We conducted ‘ecological niche modelling’ using the maximum entropy species distribution model (MaxEnt) and a multivariate analytical method to evaluate the climatic and soil integrants driving the diversity and distribution of tree species in forests, respectively. Our choice of these methods is because the MaxEnt model approach uses the connection linking species occurrence points and their linked climatic components to give a detailed account of ecological niche (climate liking) and possible geographical distribution of species (Peterson *et al.,* 2011). Various analytical methods such as

Principal Component Analysis (PCA) among others have great potential in the analysis of soil components that affect plant diversity and distribution as it includes the same data and a large number of variables. Therefore, analysis by this method gives rise to easily decipherable results (Mazlum *et al.,* 1999). Our research aims to raise awareness or the reality of climate and soil integrants that drive the diversity and distribution of forest tree species in Cross River State, Nigeria. Awareness of the ecological needs of tree species is a necessity for effective and tenable forest managing and conservancy. To this end, we assessed the diversity and distribution of forest tree species in 22 forests across northern, central, and southern Cross River State, and investigated the associated climate and soil integrant that drive the diversity and distribution.

Materials and methods

Study area

Cross River State is located in the southern zone of Nigeria (Figure 1a). The study was carried out in twenty-two forests located in the northern, central and southern zones of Rivers State, Nigeria (Figure 1b). The survey to provide field data was conducted between April 2019 and October 2020. The northern zone is part of the Tropical Dry Forest/Guinean Savanna agro-ecological zone of Nigeria and lies between latitude 6.6659716/6.654837˚N and longitude 8.7945557/8.797694˚E. The topography ranges from less than 80 to 140 m above sea level (excluding the Obudu plateau (1,700 m) altitude with threesome soil types, i.e.; clay, silt and sand (NIMET, 2015). The area has a yearly rainfall of 1,250-1,300 mm, an average yearly temperature of 30˚C, as well as a dry period of 3 to 5 months (NIMET, 2015). The central zone falls within the tropical high forest agro-ecological zone of Nigeria and lies between Latitude 6.268036/6.2467˚N and Longitude 9.029084/9.9245˚E. The terrain or forest landform in this zone is exceptionally compounded with several linked mountain arrangements, outlying summits and crops, with elevation strectching at intervals 200 m - 1300 m altitude and fast moving streams (Nsor , 2004). Soils range from clay loam to loam and generally red with high iron oxide content (Agbor, 2003). Yearly rainfall spans between 3, 000 mm - 3, 800 mm (Agbor, 2003), mean yearly temperature of 22.2˚C - 27.4˚C with mean annual relative humidity of 78% (Agbor, 2003). The southern zone belong to the tropical high forest belt agro-ecological zone of Nigeria and lies at Latitude 5.389646/5.3190˚N and Longitude 8.544654/8.3499˚E. The vegetation is mostly lowland rainforest with a rough terrain and altitude surges through the river basins to above 1, 000 mm in steep areas (Jimoh *et al.,* 2012). Lesser sandy soils are located in igneous areas, while the plains are dominated by deeper soils, while on hilly or elevated slopes they become progressively pebble, facile and corroded (Ogunjobi *et al.*, 2010). The zone has rains of not less than nine months (March – November) and receives more than 3,800 mm of rain per year (Ogunjobi *et al.*, 2010). The temperature range is 25°C - 27°C, sometimes a bit more than 30°C. Relative humidity ranges from 75 - 95%, but gradually decreases due to the dry season (Bisong & Mfon, 2006). The flora of the zone is a combination of mangroves, tropical forests and savannahs. Tropical forests are also divided into lowland tropical forests and freshwater marsh.

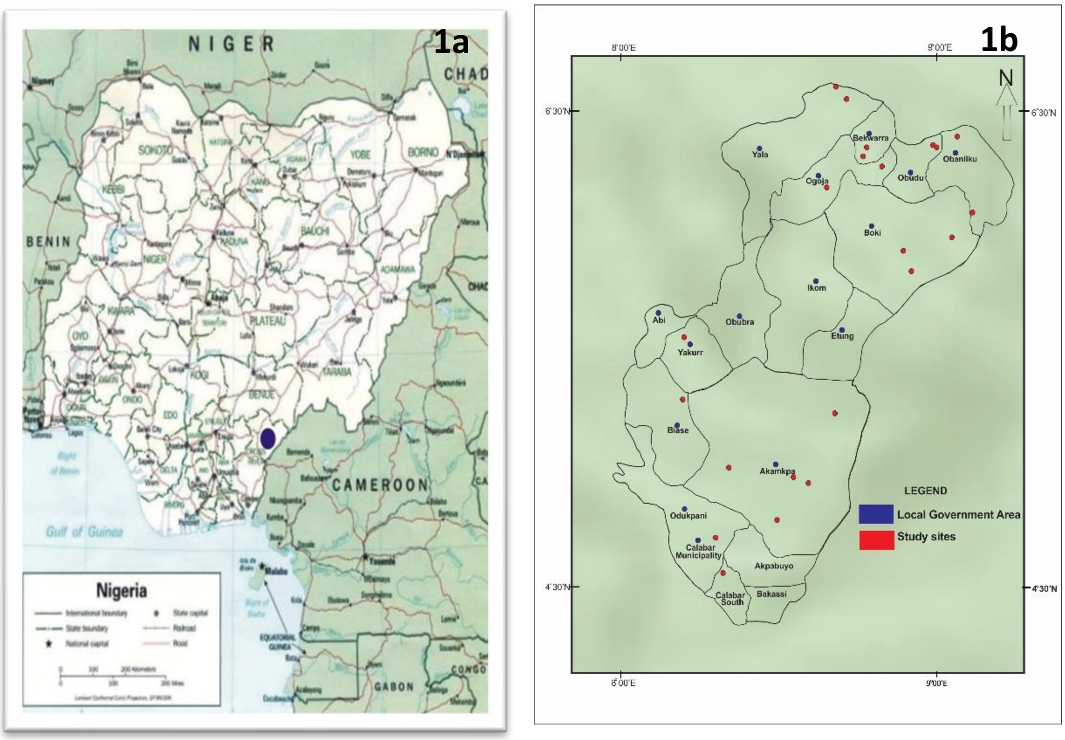


Figure 1a. Geographic map of Nigeria indicating the locality of Cross River State

Figure 1b: Cross River State map indicating study sites

Forest survey

Our study employed the Modified Whittaker sampling method (Herrick *et al.*, 2005) to survey the diversity and distribution of forest tree species. In each forest, we set up three 200m × 200m plots outlined in a spoke pattern. Inside all of these plots, a single 50m × 40m subplot followed by four 20 × 10m least subplots were set. Beginning with the least plots, all plots were surveyed and the tree species present were identified and recorded. This was augmented by the use of line transects in areas of challenging or intractable topography. Our assessment comprised listing and taking account of all free stationed trees of 30 cm and above diameter at breast height (dbh) in each plot. Forest tree species were identified using the works of Hutchinson and Dalziel (1972) and authenticated by a plant taxonomist. The dbh at a value of ≥ 30 cm and above was considered at 1.4 - 1.5m from the ground. The height of the trees was measured using a Nikon Forestry Pro Rangefinder (USA), while dbh was measured using a Diameter tape and documented following the method of Avery & Burkhart (2002). We also obtained the forest tree species diversity occurrence data.

Evaluation of climatic integrant

Our study evaluated the climatic integrant that drives the diversity and distribution of forest tree species using the occurrence points of the tree species diversity, Bioclim (environmental) variables, Quantum Geographic Information System (QGIS) software ver. QGIS-OSGeo4W-2.18.1 and Ecological niche modelling tool Maximum Entropy (MaxEnt) species distribution model ver. Jre-8u191-windows).

Species presence points or occurrence data that we use in our study are primary data obtained from our forest study. A total of 1560 recorded individual tree species geo-referenced records across the northern, central and southern zones of Cross River State were obtained and used to run the model. It is pertinent to state that some of our study sites or zones had more occurrence points of the tree species diversity than other sites or zones. It is a well-known fact that a rudimentary or primitive constraint on sample data is sample bias, in which certain sites in the area under study are sampled to a greater extent extensively than the rest (Philips *et al.,* 2009). As a means to this end, we anticipated that in our study area, where the species thrives, we may not have sampled to the same magnitude, therefore we scored deviation points on a scale of 1 (less sampling scale attempt) to 4 (largest sampling scale attempt) to represent sampling attempts in our area of study (Elith *et al.,* 2011). The above allowed us to issue bias occurrence points to run MaxEnt. The coordinates or latitude and longitude of species recorded in our sampled forests were marked with Global Positioning System (GPS) software (GARMIN GPS MAP 78 sc). Moreover, we validated each coordinates and transformed it to acquire the decimal latitude and decimal longitude using the site www.gps-coordinates.net. Species name, decimal latitude, and decimal longitude for species were computed on a Microsoft Excel spreadsheet and saved as a .csv (comma separated value) file, then used to run MaxEnt model (Philips *et al.,* 2006) as the niche model recognizes only a .CSV file. The terminal dataset of geo-referenced species records was exported into Quantum Geographic Information System (QGIS) software ver. 2.18.1 to check if any coordinates fell outside our study area.

In our study, we used fifteen downloads of basic bioclimatic variables (BIO 1 – BIO 7 as well as BIO 10 – 17) for forest tree habitats in Africa and Nigeria from the WorldClim site (https://www.world clim.org/ bioclim – Hijmans *et al.,* 2005) to drive our model. These characteristics were obtained from periodical temperature and precipitation input data over part of 1950-2000 and are loosely related or affiliated with the growth and development of species, therefore they are broadly employed in the species distribution evaluation (Elith *et al.,* 2006, Graham *et al.,* 2008, Warren *et al.,* 2013). The environmental layers from the WorldClim database must be adjusted to our research area in order to run the MaxEnt model because they cover the entire world. The precise environmental information for the area under consideration will be provided by such calibration (Philips *et al.,* 2006). To achieve this objective, we processed the environmental data for modelling by calibrating environmental layers to Africa and Nigeria using QGIS (Philips *et al.,* 2006). After clipping the occurrence data on the variables using the setting or predesigned value 1 as regularization multiplier (beta value), the BioClim variables BIO1 - 7 and 10 - 17 downloaded as Raster files were polygonized, categorized, and translated to ascii format using QGIS 2.18.1.

Amidst various programs for ecological niche modelling and habitat suitability prediction, MaxEnt is one of the highest or greatest used with reference to the sort of data used in our study, species presence-only data. This modelling tool, using presence-only data, is one of the best-performing algorithms among those using climate modelling procedures or techniques (Phillips *et al.*, 2006), and is comparatively vigorous for limited or narrow sample sizes (Pearson *et al.*, 2007). MaxEnt is a machine learning procedure that computes the distribution of species in a study area by conservative analysis of the maximum entropy probability distribution associated with the constraint that the expected value of each feature under this predicted distribution must be equivalent to its observed mean (Phillips *et al.*, 2006). In our study, the model was evaluated by using the variables per cent contribution and jackknife plots; 'Regularized training gain, test gain, and AUC' to set the largest significant dedicated variable to the model (Phillips and Dudik, 2008). The regularized training gain is used as a guide for model fitting. Regularized training gain is the size, number, or degree of interval in the middle of two or more distribution variables of any two or more random variables that exhibit correlated variation over randomly selected background plots and coincident distribution of covariates over known species plots (Elith *et al.*, 2011). As a result, an enormous regularization training gain (RTG ≥ 1) indicates an attractiveness for a limited or restricted scope of environmental conditions compared to large or large terrain, while a regularized training gain (RTG ≤ 1) indicates a specific habitat deficiency (Merow *et al.*, 2013). The test gain is, in general, an indication of how much better the model is than the random fit. A large increase ≥ 1 for a particular variable therefore means that the variable has significant prognostic value. The major advantage is that these variables are desirable predictors of where species may develop and are related to life processes (Elith *et al.,* 2006). AUC is the probability that a stochastically selected presence position of a species will be classified as more suitable than a stochastically chosen absence position (Elith *et al.,* 2006). A model is considered to have an excellent or unique performance when its AUC is close to 1 ($AUC \geq 0.75$) (Elith *et al.,* 2006). While training the MaxEnt model, we kept track of the environmental features that have a salient effect on the model. Every trace of the MaxEnt algorithm amplifies the gain of the model by changing the coefficient for a sole variable; the program allots the increase in gain to the environmental features on which the feature relies, changing or replacing them with percentages at the termination of the training process (Philips *et al.,* 2006). In this study, to test this detail, we used the recommended settings or indications that have been shown to provide vigorous or healthy outcomes as reported by Phillips & Dudik (2008). The maximum iteration was set to 1000, and the number of iterations was set to 10. The remaining substitutes are placed in default. To produce or create the terminal or ultimate maps and response curves, our model was run utilizing all data points, that is, encompassing the test data and run 50 times with bootstrapping as the duplicate run type. In the ‘bootstrapping’ synchronization procedure the training data is chosen at random with the addition or substitution via the occurrence points. Where the quantity of samples matches the total number of presence points (Phillips, 2010). This alternative would recompense for the smaller number of sites present in the study area.

Evaluation of soil integrant

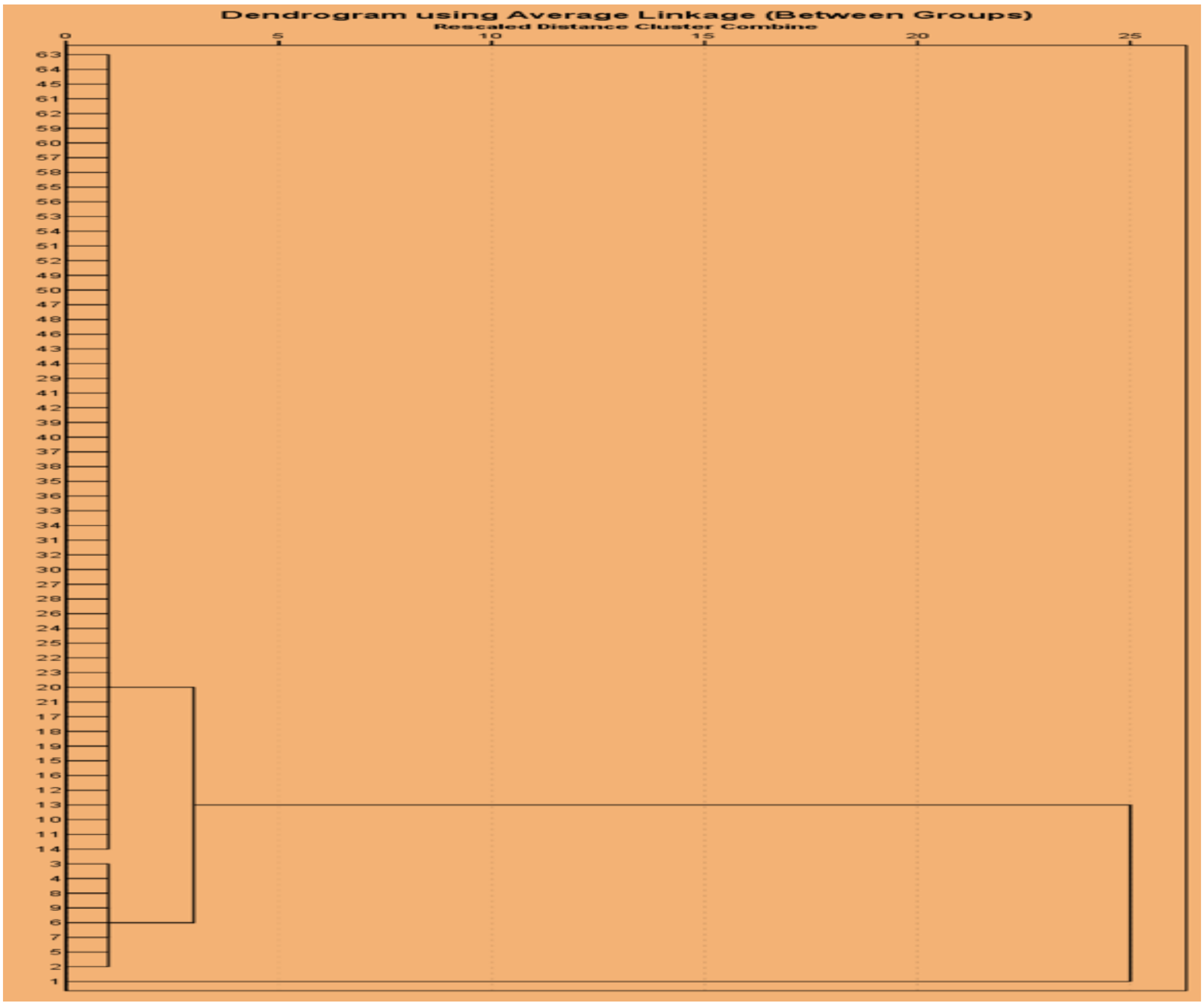
Soil parameters were evaluated from ten soil samples collected randomly in each of the surveyed plots in the twenty two forest areas (north, central and south) of Cross River State. We took soil samples with a soil drill (augre) at a root depth of 15 - 50 cm during the rainy season (April - October), packed in polyethylene bags and studied at the soil science laboratory, Department of Soil Science, University Calabar, Calabar, Cross State River, Nigeria for soil physico-chemical integrant. Twenty three soil components were studied. Soil texture was ascertained by Bouyoucous hydrometer method (Bouyoucous, 1951). pH was calculated in a 1:1 soil-water scale utilizing a digitized pH meter (EDT-BA350). Organic matter were determined by the wet oxidation of dichromate as proposed by Nelson & Sommer (1996). Total N (Nitrogen) by the micro-Kjeldahl method (Jackson, 1965). Available Phosphorus by Bray P-1 method (Bray & Kurtz, 1945). Soil trace elements such as zinc (Zn), lead (Pb), manganese (Mn), iron (Fe) etc. were analysed using WD-XRF method (Beckhoff *et al.,* 2007). Conductivity was calculated in the extract obtained from soil 1:2.5: water suspension using conductive bridges. Exchangeable cations (Ca2+, Mg2+, K^+ and Na^+) were isolated using 1N ammonium acetate (NH4OAc) absorbed at pH 7.0 (Thomas, 1996). Exchangeable potassium (K) and Sodium (Na) via a flame photometer (Jenway PFP7). Ca and Mg were explored using Atomic Absorption Spectrophotometer. Exchange acidity was determined with I N KCl and calibrated by titrating with 0.05 N NaOH utilizing phenolphthalein indicator (McClean, 1982). ECEC was gotten by summing-up of exchangeable cations and Per cent Base saturation calculated as Exchangeable Bases x 100/ECEC × 1

We performed principal component analysis (PCA) for twenty two sampling sites (forests) grouped into the northern, central, and southern zones of Cross River State. Our choice to perform PCA per zone is due to the fact that the zones have different soil properties and also gives us a clearer picture of the soil variables that affect each zone. Two data matrices were used, composing vegetation; diameter at breast height (dbh) and height of the tree species and soil characteristics (physico-chemical properties) were built for each zone, and the software package SPSS for windows (ver.21) was used for execution. PCA was conducted to detect the main soil integrant driving forest tree species growth, variation and dispersion. PCA resolved the effects of soil on vegetation (Jafari *et al.,* 2003), and principal components were contemplated functional if both total or accumulated per cent variation measured up to 50% and above (Li *et al.,* 2008). We used the plot of conventional components from PCA output to elucidate the principal soil integrant that drives the diversity and dispersion of tree species in forest vegetation. Our usual component plots for the integrant were discovered utilizing variance optimization; the method has been used because it aids in reducing the multiplicity of components by creating huge and small loads within each component (Chatfield & Collin, 1980; Muzlum *et al.,* 1999; Wuensch, 2006). The goal of variance optimization is that individual integrants need to load on one or two components as practicable to make the explanation easy (Stephens, 1986; Field, 2005). To discover the essential integrant, only the integrant selected on the principal component plot was justified as significant (Johnson, 1980; Kent & Coker, 1992).

Results

Forest tree species composition across Cross River State

An aggregate of 1560 individuals belonging to 398 tree species and 64 families were recorded in the twenty-two sampled forests from the northern, central and southern zones of Cross River State, Nigeria. A summary of tree species families recorded in the sampled forests is presented in Figure 2. The dendrogram (Fig. 2) shows the paired cluster analysis of 64 families of tree species recorded in the study area based on Euclidean distance. The dendrogram shows two major clades with 63 families in clade 1 within 5% and Fabaceae in clade 2 at 25% Euclidean distance, respectively. Clade 1 is further divided into subclade 1a with 55 families (Gentianaceae, Ebenaceae, Clusiaceae, Anacardiaceae, Combretaceae, Salicaceae, Cannabaceae, Rutaceae, Olacaceae, Lamiaceae, Chrysobalanaceae, Bignoniaceae, Ochinaceae, Lecythidaceae, Irvingiaceae, Buseraceae, Sapindaceae, Passifloraceae, Myristicaceae, Urticaceae, Tiliaceae, Putranjivaceae, Polygaceae, Pandaceae, Myrtacaceae, Melastomacaceae, Loganiaceae, Lauraceae, Ericaceae, Connaraceae, Calophyllaceae, Bombacaceae, Arecaceae, Araliaceae, Agavaceae, Violaceae, Sterculiaceae, Simaroubaceae, Rhizophoraceae, Rhamnaceae, Pandanaceae, Octoknemaceae, Moringaceae, Lepidobotryaceae, Juglandaceae, Hypericaceae, Huaceae, Clusiaceae, Flacourtiaceae, Elaeocarpaceae, Dichapetalaceae, Boraginaceae, Asteraceae, Anisophyllaceae and Achariaceae) and subclade 1b with 8 families (Sapotaceae, Moraceae, Euphorbiaceae, Phyllanthaceae, Apocynaceaea, Annonaceae and Meliaceae and Malvaceae) at less than 5% Euclidean distance. The families that made up subclade 1a had tree species population of 1 - 8 while subclade 1b had 14 – 29, respectively. The Fabaceae family therefore recorded the greater number of forest trees (64) and was the most dispersed across the forests sampled in Cross River State.



Key:

1 - Fabaceae, **2** - Malvaceae, **3** - Sapotaceae, **4** - Moraceae, **5** - Meliaceae, **6** - Apocynaceae, **7** - Annonaceae, **8** - Euphorbiaceae, **9** - Phyllanthaceae, **10** - Gentianaceae, **11** - Ebenaceae, **12** - Clusiaceae, **13** - Anacardiaceae, **14** - Combretaceae, **15** - Salicaceae, **16** - Cannabaceae, **17** - Rutaceae, **18** - Olacaceae, **19** - Lamiaceae, **20** - Chrysobalanaceae, **21** - Bignoniaceae, **22** - Ochinaceae, **23** - Lecythidaceae, **24** - Irvingiaceae, **25** - Buseraceae, **26** - Sapindaceae, **27** - Passifloraceae, **28** - Myristicaceae, **29** - Urticaceae, **30** - Tiliaceae, **31** - Putranjivaceae, 32 - Polygaceae, **33** - Pandaceae, **34** - Myrtacaceae, **35** - Melastomacaceae, **36** - Loganiaceae, **37** - Lauraceae, **38** - Ericaceae, **39** - Connaraceae, **40** - Calophyllaceae, **41** - Bombacaceae, **42** - Arecaceae, **43** - Araliaceae, **44** - Agavaceae, **45** - Violaceae, **46** - Sterculiaceae, **47** - Simaroubaceae, **48** - Rhizophoraceae, **49** - Rhamnaceae, **50** - Pandanaceae, **51** - Octoknemaceae, **52** - Moringaceae, **53** - Lepidobotryaceae, **54** - Juglandaceae, **55** - Hypericaceae, **56** - Huaceae, **57** - Clusiaceae, **58** - Flacourtiaceae, **59** - Elaeocarpaceae, **60** - Dichapetalaceae, **61** - Boraginaceae, **62** - Asteraceae, **62** – Anisophyllaceae, **64** - Achariaceae

Figure 2. Dendrogram of paired cluster analysis using average linkage (between groups) of 64 families of recorded forest tree species based on Euclidean distance

Climatic integrants driving forest tree species diversity and distribution across Cross River State

In this study, the charts of variable importance (Figure 3 i, ii and iii) and the table of variable ratio input and order of significance (Table 1): this action or standard depends entirely on the final series of the MaxEnt model, not the route or pathway used to achieve this. The role played by the individual climate feature is adjusted by arbitrarily changing the placement order of that feature's values amidst the training points; 'presence and background' and computing the connected reduction in training AUC. A high reduction specifies that the model is strongly dependent on this feature; Features are interpolated to obtain per cent) identified six climatic integrants; ‘BIO 3 – Isothemality’, ‘BIO 4 - Temperature seasonality’, ‘BIO 7 - Temperature annual range’, ‘BIO 12 - Annual precipitation’, ‘BIO 16 - Precipitation of wettest quarter’ and ‘BIO 17 - precipitation of driest quarter’ as playing the greatest part of the range or distribution area of the forest tree species diversity throughout Cross River State. Variable importance charts supported that removing any of these six integrants did not allow for optimization compared to using the entire feature set (training gain, AUC, and testing gain). Consistent with the variable influence charts, the input variable ratio table for the forest tree species diversity (Table 1) shows that BIO 16 was the most significant defining or influencing integrant among the six integrantss reserved in the model. BIO 17 reduced the gain the greatest when excluded and noticeable to be the greatest revealing integrant to the model.

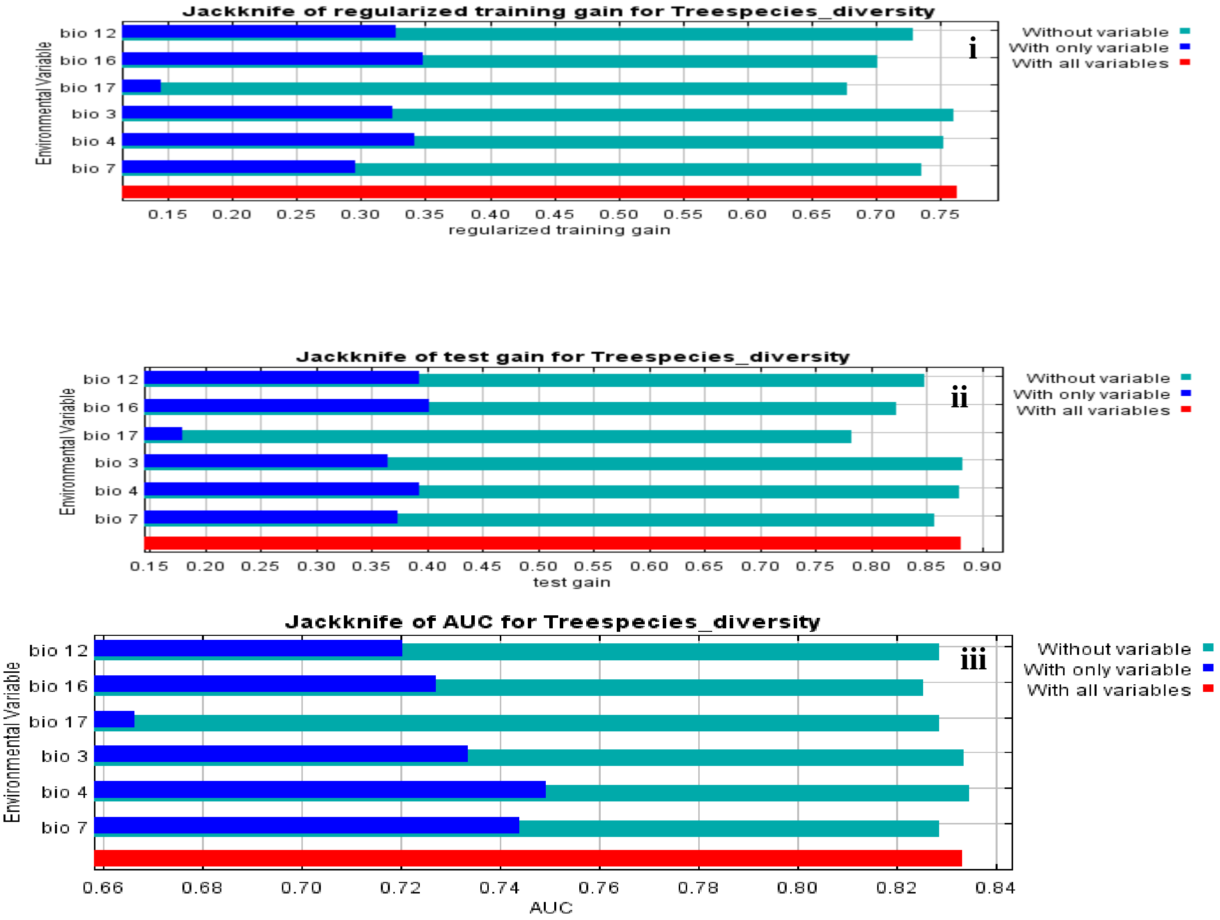


Figure 3. Most significant climatic integrant driving forest tree species diversity and distribution

Table 1: Ratio input and order of significance of the most significant climatic integrant

Climatic variables	Ratio input (%)	Order of significance
Precipitation of wettest quarter ‘Bio 16’	34.4	10.5
Precipitation of driest quarter ‘Bio 17’	24.8	2
Temperature seasonality ‘Bio 4’	19	11.8
Temperature annual range ‘Bio 7’	11.6	14.5
Annual precipitation ‘Bio 12’	6.9	46.2
Isothermality ‘Bio 3’	3.2	15.1

The reaction curves of this climatic integrant to the prediction of aptitude or validity of the diversity of forest tree species are presented in Figures 4 i, ii, iii, iv, v and vi. Isothermality (BIO 3) (Figure 4i) apparently determines the susceptibility or tolerance of the forest tree species diversity to monthly fluctuations in daily versus annual temperature. The logistic prediction shows that prediction of greater suitability to forest tree species diversity corresponds to about 66 - 75% change in temperature of diurnal monthly amplitude from annual diurnal temperature. Thus, the diversity and distribution of forest tree species are associated with maximum or long-range fluctuations in monthly daily temperature and not annual (100%). The reaction curve of forest tree species diversity with seasonal temperature (BIO 4) (Fig. 5ii) shows that the highest forest tree species diversity are associated with the lowest or smallest seasonal temperature from 1 to 14% and greater values are in all probability to determine the boundaries of the forest trees presence. Th reaction curve of the forest trees to the annual range of temperature (BIO 7) (Figure 5iii) shows that the highest probabilities of presence of forest tree species are connected to the smallest fluctuation from 1 to 13% and the values more in heights probably delimit the presence of the forest trees. The forest trees reaction curve with annual precipitation (BIO 12) (Fig. 5iv) corresponds to the environment (ecology) for the forest tree s as defined by precipitation values from 1000 mm to 2700 mm and sharply declining to optimally 3800 mm or effective values of suitable tree species high or predictable validity. The forest trees reaction to precipitation in the wettest quarter (BIO 16) (Figure 5v) shows excellent response performance, with an increase in precipitation from 400 to 1000 mm and a sharp decline after the fitness threshold of about 1400 mm. The reaction curve of the forest trees to precipitation of driest quarter (BIO 17) (Figure 5vi) shows good response output from 0 to 100 mm and then a sharp decline after the suitability threshold from after 200 mm. The resulting forest trees reaction curves further show that the forest trees are sensitive to periods without moisture (dry) and moisture (wet) seasons in their accustomed or established habitat.

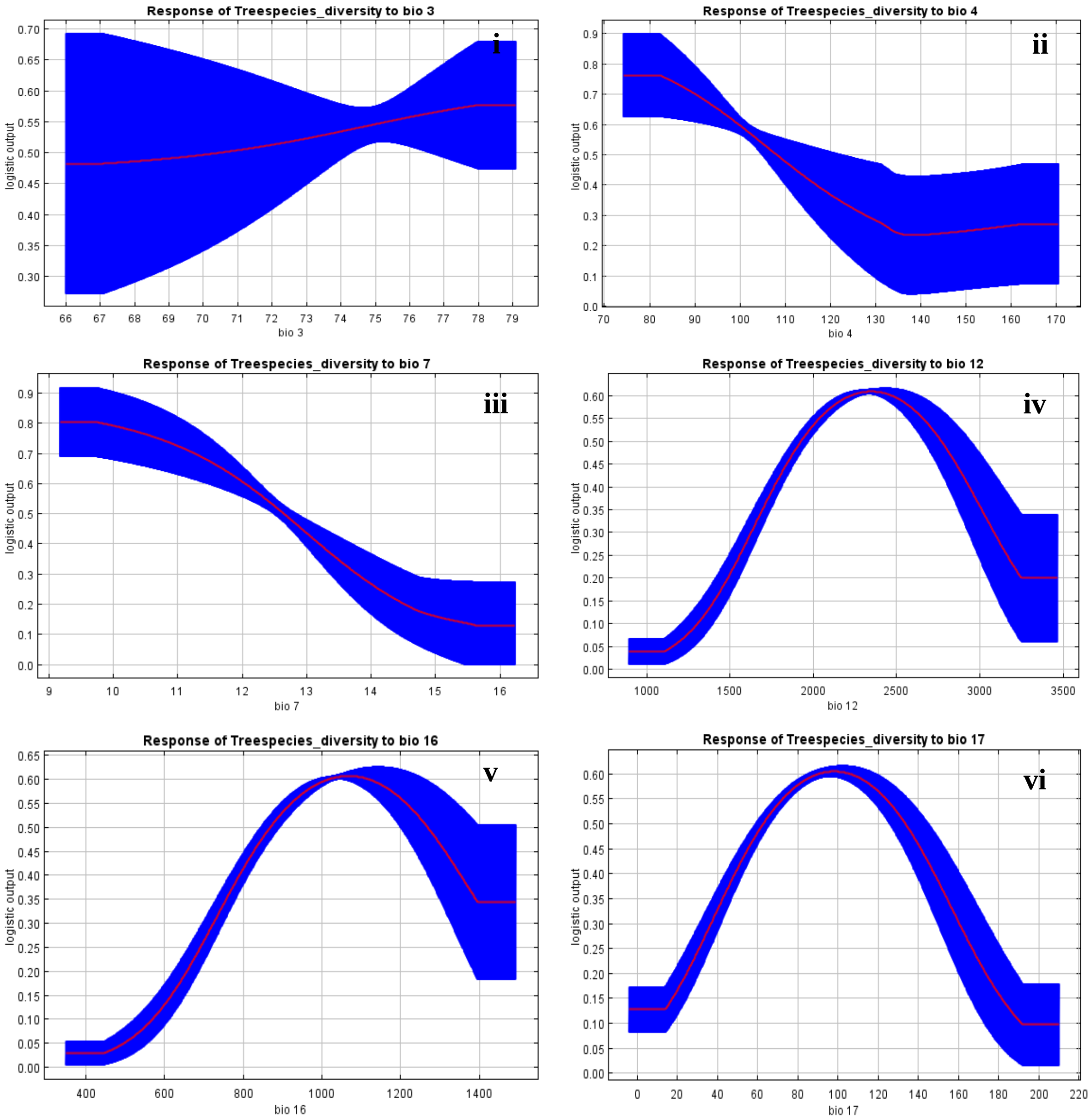


Figure 4. Reaction curves of the climatic integrant that drive the growth and distribution of the forest trees

Soil integrants driving forest tree species diversity and distribution across Cross River State

Principal component analysis (PCA) was executed or accomplished using two tree species vegetation framework; ‘diameter at breast height (dbh) and height (Ht)’ (Table 2) as well as twenty-three soil characteristics at twenty-two sampled locations clustered in the northern, central and southern zones of Cross River State, Nigeria. PCA was performed to discover the foundational soil integrant that enhanced the forest trees growth, diversity and distribution in the various zones. Component plots and per cent of variance were constructed for the soil integrant. In the northern zone, the principal component plot of soil integrant that drive forest trees growth, diversity and distribution is presented in Figure 5. Predicated on the principal component plot, five soil integrants were selected significantly on component 1, the integrant are Iron, Available Phosphorus, Manganese, exchangeable cation and Silicon. These integrant attributed for 25.97% of the variance in the soil data. Component 2 had two soil integrant; these include Hydrogen ion and organic matter and they attributed for 20.96% of the variance in soil data, respectively.

Table 2. Mean dbh and height of forest tree species sampled across northern, central and southern zones of Cross River State

S/N	Sampling locations (Zones)	Mean dbh (cm)	Mean height (m)
1.	Gabu Community Forest (NORTH)	39.4487	15.4026
2.	Aliforkpa Community Forest (NORTH)	35.5714	15.3
3.	Winniba-Ekajuk Community Forest (NORTH)	37.7554	16.3375
4.	Aragban Community Forest (NORTH)	38.2645	16.5371
5.	Ukpa Community Forest (NORTH	51.8683	17.8833
6.	Okpeche-Afrike Community Forest (NORTH)	58.6815	19.5415
7.	Alege/Utugwang Community (NORTH)	55.9765	19.2235
8.	Bebuabong/Ohong Community (NORTH)	56.8508	19.9
9.	Becheve Forest Reserve (NORTH)	95.833	27.6738
10.	Sankwala Community Forest (NORTH)	66.6628	21.166
11.	Cross River National Park Okwangwo (CENTRAL)	195.138	52.9614
12.	Mbe Mountain Community Forest (CENTRAL)	63.7934	20.911
13.	Afi Mountain &Wildlife Sanctuary (CENTRAL)	129.782	36.0893
14.	Agoi Forest Reserve - Agoi-Ibami (CENTRAL)	85.67	26.2583
15.	Agoi Forest Reserve - Abini (CENTRAL)	85.62	26.2579
16.	Cross River National Park Oban (SOUTH)	174.8063	48.2951
17.	Oban Forest Reserve (SOUTH)	70.8316	21.7211
18.	Kwa Falls (Aningeje) (SOUTH)	82.6393	25.9713
19.	Ekuri Community Forest (SOUTH)	88.6393	27.1054
20.	Ekong Anaku Community Forest (SOUTH)	44.9048	15.6581
21.	Adiabo Community (SOUTH)	45.3615	15.6846
22.	Idim Ita Community (SOUTH)	28.6733	13.9033

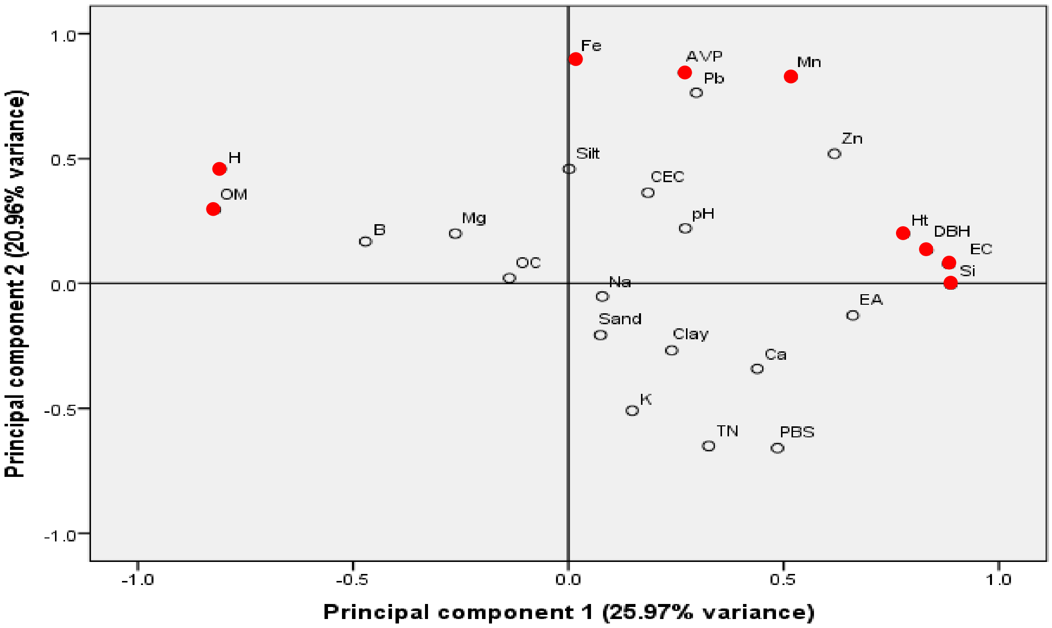


Figure 5. The principal component plot of soil integrant that drives forest tree growth, diversity and distribution in Northern Cross River State

In the central zone, the principal component plot of soil integrant that drives forest tree growth, diversity and distribution is presented in Figure 6. Predicated on the principal component plot, six soil integrants were selected significant on component 1, the variables are Zinc, Organic matter, exchangeable cation, Total Nitrogen, Sodium and Boron. This integrant contributed to 33.09% of the variance in the soil data. Component 2 had four soil integrants; these include Clay, pH, Exchangeable acid and Silicon and attributed for 30.72% of the variance in soil data, respectively.

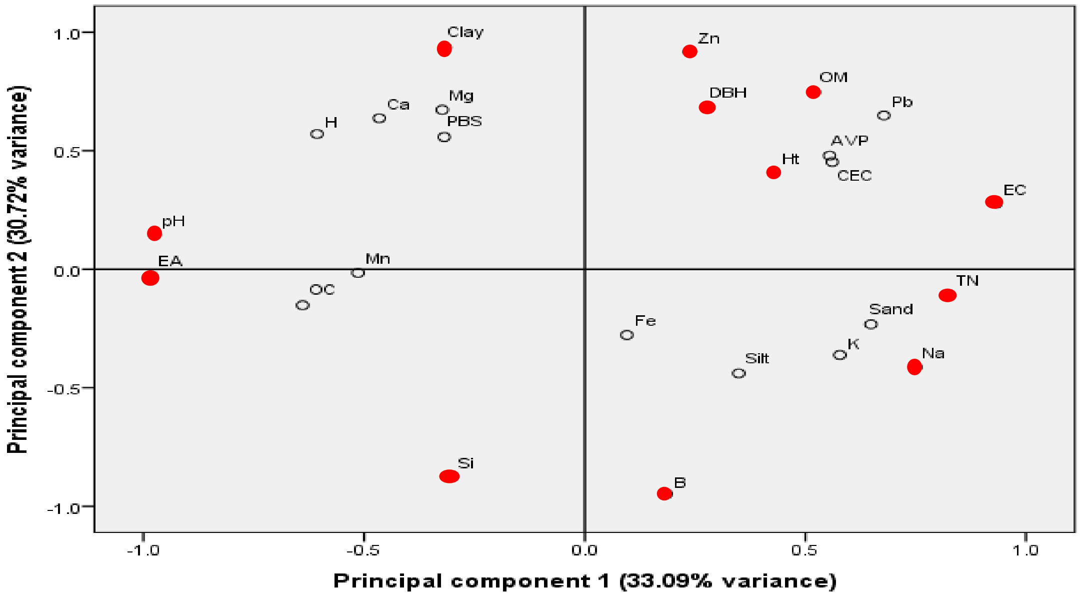


Figure 6. The principal component plot of soil integrant that drives forest tree growth, diversity and distribution in Central Cross River State

In the southern zone, the principal component plot of soil integrant that drives forest tree growth, diversity and distribution is presented in Figure 7. Predicated on the principal component plot, five soil integrants were selected significantly on component 1, the integrants are sand, silt, organic carbon, Magnesium and Hydrogen ions. This integrant contributed to 31.37% of the variance in the soil data. Component 2, had four soil integrants; these includes Calcium, cation exchange, Potassium and clay and accounted for 21.44% of the variance in soil data, respectively.

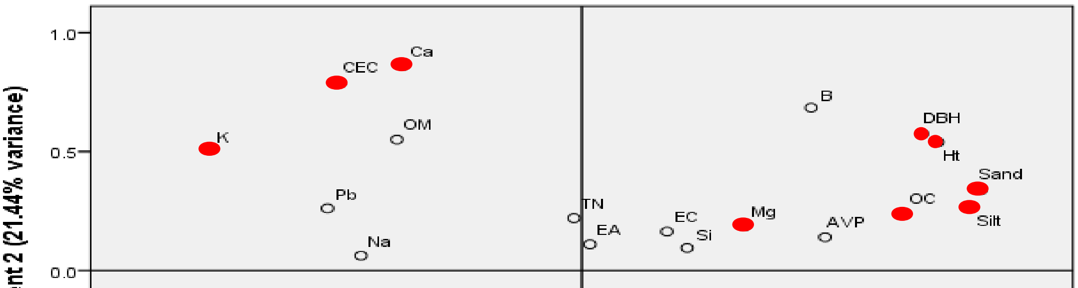


Figure 7. The principal component plot of soil integrant that drives forest tree growth, diversity and distribution in Southern Cross River State

Discussion

Forest tree species composition

Our study assessed forest tree species diversity and distribution in twenty-two forested areas comprising the northern, central, and southern parts of Cross River State, Nigeria. The distribution of forest tree species diversity in the forests in our study using occurrence points is shown in Figure 2. An aggregate of 1560 individuals belonging to 398 tree species and 64 families were documented in the sampled forests. The wide range of species and family variations (Figure 2) recorded through the forest survey showed significant variation. The aggregate of forest tree species diversity documented in our study area is not very different from reports in other tropical forest biomes. For example, Lu *et al.,* (2010) reported 428 trees belonging to 38 families in the rainforests of Xishuangban, China, and Rajkumar and Parthasarathy (2008) reported 415 species belonging to 32 families in Andaman Giants, India. Small *et al.,* (2004) reported 422 tree species for Borneo and up to 544 were reported for primary forests in Indonesia by Kessler *et al.,* (2005). However, the total tree species recorded in our study (398 of 65 families) was higher than 347 of 42 families in a Mexican tropical forest reported by Duran *et al.*, (2006), 245 trees were reported for tropical forests by Campbell *et al.,* (1992), 247 tree species recorded for a matured tropical forest in Southeast Asia (Losose and Leigh, 2004), 92 species in a submontane tropical rainforest in the Philippines (Hamann *et al.,* 1999) and a mature forest 81 species of lowland dense forests in Vietnam (Blanc *et al.,* 2000). Of the 398 forest tree species variations documented in our study, the family Fabaceae was the most frequently encountered, with a diversity of 64 tree species. The greater variety of legumes may be due to their rapid sprouting capability as well as the tenacity of seeds in soil banks. As reported by Ihenyen *et al.,* (2009) the family Fabaceae was the most frequent with eighteen species in the Ehor Forest Reserve, Edo State, Nigeria. Omorogbe (2004) recorded Fabaceae family had the greatest diversity in Sakponba Forest Reserve, Edo State, Nigeria with fourteen tree species. Additionally, researchers like Aigbe *et al.,* (2014), Aigbe & Omokhua (2015), Wakawa *et al.,* (2017) and Amonum *et al.,* (2016) made similar observations on legumes in the Afi River Forest in Cross River State, Nigeria, the Oban Forest Reserve, the Sahel Ecosystem in the northeast, and the Nengji Forest Reserve in Benue State, Nigeria, respectively. The fewest species are found in the families' Achariaceae, Anisophyllaceae, Asteraceae and 17 others. The fewer aggregate of forest tree species observed in these families may be due to poor germination as the seeds may show some dormancy which might need scratching or modification in thermic or luminous environments to overcome. Pausas & Austin (2001) reported that these environmental conditions may have effects on species richness. Additional restricting components encompass the angular light of canopy trees, the extermination of vegetation on the forest floor in the course of logging, nutrient build-up as well as other anthropogenic factors (Egbe *et al.*, 2012).

Climatic integrant driving forest tree species diversity and distribution across Cross River State

The variation and dispersion of plant species in a physical feature of an area is dictated by a complex network of living and non-living factors or conditions. These circumstances include the climatic conditions prevailing in an area, soil attributes, competition within and between individuals, human-caused disturbance, and dispersal restriction (Blach-Overgaad *et al.,* 2010). Climatic variables are the key or primary indicators of the living environment of species, on the other hand, dispersion restrictions as well as species interplays could also alter distributions (Soberón & Peterson, 2005). An adequate understanding of the climatic conditions of a species is absolutely critical to evaluate the wide spatial range in which it can thrive and to assess its likely reaction to climate change for conserving and managing goals (Bowe & Haq, 2010). Based on the ecology of forest tree species diversity recorded in our study, the vast majority of forest tree species are native to the dense moist tropical rainforest zone of West and Central Africa (Oboh, 2007; Orwa *et al.,* 2009). The recorded forest tree species are habitual in primary and secondary forests and dry/coastline savannahs, oftentimes near rivers and creeks (Orwa *et al.,* 2009), at an altitude of 500 - 1000 m and need yearly rainfall of 1000 - 3000 mm or more with a mean yearly temperature of 25 - 32˚C (Orwa *et al.,* 2009). Our study identified six climate integrants that drive or influence forest tree species diversity and distribution in Cross River

State, Nigeria. These are ‘Isothemality (BIO 3)’, ‘Seasonal temperature (BIO 4)’, ‘Annual temperature range (BIO 7)’, ‘Annual precipitation (BIO 12)’, ‘Precipitation of wettest quarter (BIO 16)’ and ‘Precipitation of driest quarter (BIO 17)’. Therefore, we found that the climatic integrant that drives the forest tree species diversity and distribution in our study area can be categorized into two groups; temperature and precipitation or rainfall. Our result is consistent with the work of Rowe (2009) that climate integrants like temperature in conjunction with precipitation are critical factors to directly drive species diversity and distribution. In addition, Wright *et al.,* (1993) and Hawkins *et al.,* (2003) reported that specific of the greatest key or fundamental designs in ecology is the option of a wide-ranging distinction in the aggregate of different species existing in a region or an ecological environment with such climates factors like temperature and rainfall. Furthermore, Woodward (1987) stated that climate is a key aspect driving the diversity and distribution of plant species while Mariseau *et al.,* (2011) reported that climate is the stable driver of tree and forest growing rates. The discovery of our study is for that reason dependable with consideration to the ecology of the forest tree species diversity. In fact, the annual precipitation (BIO 12) and its precipitation variation of the wettest quarter (BIO 16) and driest quarter (BIO 17) were the largest contributors to the model. On a broad scale, species diversity and distribution are mainly dependent on climate (Vayreda *et al.,* 2013) and exclusively on water-related variables (Svenning and Skov, 2006). Annual precipitation (BIO 12) is roughly equivalent to total annual water input (precipitation) (O'Donnell & Ignizio, 2012). According to our model, it was found that annual precipitation of 1000 - 2700 mm and a sharp decline to 3800 mm is suitable for the forest tree species diversity and distribution across forests in our study area, which is, in addition, constant with the ecology of the forest tree species diversity. Broadly, precipitation affects taxa richness (ter Steege *et al.,* 2006), diversity (Hall & Swaine, 1996) and distribution (Swaine 1996; Bongers *et al.,* 1999; Engelbrecht *et al.,* 2007). Amissah *et al.,* (2014) found that almost all forest tree species at 95% were significantly influenced by yearly rainfall and that yearly rainfall shed extra light on the mean 17% variant in species existence. Overall, tree growth rises with rainfall (Murphy & Lago, 1986; Dauber *et al.,* 2005) and lowers with drought (Nath *et al.,* 2006; Lola da Costa *et al.,* 2010). Water has several purposes in the plants and is established to influence the distribution designs of species at local scales (Willis & Whittaker, 2002) in comparison to worldwide scales. It is able to dissolve other substances for mineral nutrients and the network of organic matters manufactured inside the plant; in addition functions as a temperature adjuster throughout the course of plant exhalation of water vapour through the stomata and acts as raw material in the procedure of photosynthesis which is the essential process fundamental to all life (Ferguson, 1959). Plants can be troubled by the absence of moisture in addition to an excess of moisture (Haferkamp, 1987). Considering those significant tasks, the existence of water in the environment of plants is absolutely of high priority. Precipitation of the wettest quarter (BIO 16) supplies all or the whole rainfall in the course of the wettest three months of the year, while precipitation of the driest quarter (BIO 17) supplies all or whole rainfall in the course of the driest three months of the year (O'Donnell & Ignizio, 2012). Our findings revealed that the maximum probabilities (>0.5) for the existence of forest tree species diversity were attained at 400 - 1000 mm and 0 - 100 mm for precipitations of the wettest and driest quarters, respectively. This means that the higher values of BIO16 (wettest 3 months) of the year will sway or explain the forest tree species diversity and the evolution of distribution. Likewise, higher values of BIO 17 (driest 3 months) of the year will affect or say the growth of forest tree species diversity and distribution. Higher values of BIO 17 can be attributed to or linked to water scarcity or drought for the evolution of forest tree species diversity. Drought is the greatest symbolic ecological stress in plant growth globally. Drought activates water shortfall or deficiency that is certain to be injurious for plants and bring about amongst others, a reduction in stem expansion, a decline in photosynthetic production and then lessen plant growth, development, survival and productivity (Boyer, 1982; Cattivelli *et al.,* 2008; Ings *et al.*, 2013). The reaction of forest tree species diversity to annual precipitation variations; BIO 16 and BIO 17 in our study area further suggest that the forest tree species diversity is sensitive to the lack of moisture (dry) and moisture (wet) season in their habitual range as the forest tree species diversity are common in primary and secondary forest and guinea savannah (Orwa *et al.,* 2009). Although mean annual temperature (BIO 1) is not amongst the greatest significant supportive integrants for the diversity and distribution of the forest tree species, its variation in isothermality (BIO 3), seasonal temperature (BIO 4) and annual temperature range (BIO 7) demonstrated to significantly drive the geographic diversity and distribution of the forest tree species. It is imperative to accentuate here that the speed of plant growth and development is superintend by its terrain temperature and each plant has a clearly defined temperature range distinguished by a minimal, high and optimal (Hatfield & Prueger, 2015). Isothermality (BIO 3) measures or assesses how much day-night temperatures vary compared to yearly fluctuations (O'Donnell & Ignizio, 2012). The logistic prediction of the response curve and the maximum probability (>0.5) of the existence of our forest tree species diversity was attained with values of BIO 3 at intermediate 66 - 75%, falling below average to high of variables. The highest mean value of the variable being 100% specifies the diurnal temperature range is identical to the yearly temperature range (O'Donnell & Ignizio, 2012). The isothermal or equatorial climate is a year-round hot and humid climate that has an average temperature range of 26.7 to 28.2˚C and a yearly precipitation of 2300 mm (Koppen, 1918). Therefore, the isothermal response curve (BIO 3) confirms that day-to-night temperatures suitable for the forest tree species diversity and distribution oscillate in the mid-27–29 °C for annual fluctuations which again correspond to the ecology of the forest tree species in our study area. Temperature seasonality (BIO 4) is a measure of temperature change throughout the year based on the standard deviation of monthly mean temperatures (O'Donnell & Ignizio, 2012). The maximum probability of variation of our forest tree species (>0.5) achieves the seasonal value of BIO 4 at the centre of 1–14%, which combines as the least variable of seasonal temperature. The annual temperature range (BIO 7) is a measurement of temperature differences over a given period. It examines whether species distribution is affected by the extreme temperature range (O'Donnell & Ignizio, 2012). The maximum probabilities of the existence of forest tree species diversity (>0.5) are associated with the smallest range from 1 to 13%, which also adds up to the smallest temperature variations. This suggests that higher values likely limit the existence of forest tree species diversity and distribution. According to Hatfield & Prüger (2015), vegetative growth rises and multiplies as temperatures rise to species-optimal levels, and for more plant species, vegetative growth typically has a greater optimal rate than reproductive growth. Taking into consideration their findings it can be understood that immense differences of temperature such as high value of BIO 4 and BIO 7, can affect the optimal temperature of the forest tree species diversity and next influence on the distribution and growth either at vegetative and reproductive stages. Consequently, it can be concluded that the highest values of temperature seasonality (BIO 4) and temperature annual range (BIO 7) at which the distribution of forest tree species diversity can be negatively affected are 14 and 13%, respectively. According to Elith *et al.,* (2011) abstraction of a model relies on the alternative of features used to run it. In this study, the variable BIO 3, BIO 4 and BIO 7 determined accessibility and changeability of light and temperature (heat) to the forest tree species diversity and distribution while BIO 12, BIO 16 and BIO 17, respectively, measured the accessibility and changeability of rainfall (water) for the forest tree species diversity and distribution. Because the characteristics that drive or influence the geographic diversity and distribution of forest tree species are foundational conditions, our model might be generalizable to areas independent of our study area and to target species managing in such geographic areas (Elith *et al.*, 2011).

Soil integrant driving forest tree species diversity and distribution across Cross River State

The forest, as a biological community composed of interacting organisms and their physical environment, generally exhibits assortments of soils with different characteristics. A few of certain soil features crop up more essential than others and perform a distinct function in distinguishing the soils that cover a particular area. Understanding the factors of selection or isolation among many distinct soil characteristics is functional for managing forests (Salehi & Zahedi Amiri, 2005). Principal component analysis (PCA) is a functional data-decreasing procedure that operates by detaching interconnection between variables or components. By using PCA, not only is the integer of juxtaposition in the middle of treatment averages lessened, but the quality of having great value or significance of these components is magnified. In our study, PCA explicitly distinguished soil features between soil profiles or descriptions in forest ecosystems (Mesdaghi, 2001). In our study, by using PCA, the broad, mutual soil properties originally contemplated to govern soil and vegetation correlations were decreased to a small number of uncorrelated and augmented fundamental components. This is because PCA is a reality search engine that lessens quantitative problems including bias and simplifies correlated data as only meaningfully useful variables are retrieved between sets of variables or rational principal elements which gives an explanation for nearly all of the variants examined components (Henson & Smith, 2000; Kfis *et al.,* 2010). Our PCA results show that the influence of soil on vegetation is controlled by diverse sets of soil characteristics across different zones of the North, Central and Southern Cross River State. In our study, two basic parameters of tree species vegetation were used for PCA analysis, which strengthen support and enhance the soil to maintain tree species recovery ability. These include the dbh and the height of the tree species. These variables stand out as a vegetation climate framework that protects the soil from various climate circumstances such as massive storms, soil erosion containment as well and soil moisture conservation amongst others. These frameworks additionally help maintain soil fertility via biomass accumulation and ensuing decomposition; the impacts of their interaction on soil structure are symbolized by variations in the mineral constituents of the litter and the hydrological effects of the canopy. Our PCA results show that seven basic soil integrants (iron, Available Phosphorus, manganese, Exchangeable cations, silicon, Hydrogen ion and organic matter) drive the growth characteristics, diversity and distribution of forest tree species in the northern zone. In the central zone, ten key soil integrants were identified (zinc, organic matter, Exchangeable cations, Total Nitrogen, Sodium, boron, clay, soil pH, Exchangeable acids and silicon). In the southern zone, nine soil integrants (sand, silt, organic carbon, Magnesium, Hydrogen ion, Calcium, Cation exchangeable capacity, Potassium and clay) drive the growth, diversity and distribution of forest tree species. Several researchers have reported that soil physical and chemical characteristics can inform vegetation outgrowth on a geographical scale (Olivera-Filho *et al.*, 1998; Hejkmanova-Nisrkova and Hijkman, 2006; Han *et al.*, 2011; Zhao *et al.*, 2015). Tree growth, distribution of species, and diversity in tropical regions are driven by soil nutrients (John *et al.*, 2007; Santiago *et al.*, 2012). Furthermore, our findings somewhat corroborate those of Aweto (1981) who reported, organic matter, soil pH, sand proportion, total nitrogen, clay, silt, bulk density/porosity and potassium as key soil elements driving species diversity and distribution. In addition, our findings are related to those of Yahya *et al.*, (2008), who reported that soil properties like organic matter, clay, silt, conductivity, nitrogen, phosphate Phosphorus and carbon affect tree growth and distribution in the South Caspian forests of Northern Iran. Soil properties such as organic matter and tree size are related; the significance of tree size is evident in this interrelation, as higher tree size could catalyse increased nutrient accumulation in the forest by multiplying litter manufacturing and shielding the soil from increased nutrient decimation (organic matter) as well as loss from erosion. This suggests ameliorating the constituents of organic matter in the soil by the inclusion of nutrients in solution form via stem flow and via the build-up and decay of litter. As reported by Foth (2006), huge organic matter content in soil is the outcome of gradual rates of decomposition instead of high levels of organic matter incorporation. Our study area benefits from high precipitation and temperature, which unclogs the fast decay of litter, thus multiplying the proportions of organic matter inclusion. Additionally, several studies have shown that soil organic matter is involved in monitoring environmental variables and plant communities in forests (Zhang and Zhang 2007; Silk *et al.*, 2009; Sarker *et al.*, 2014; An *et al.*, 2015, Zhang *et al.*, 2016) and contribute to the supply of nutrients and water by enhancing soil organization and physical condition, increase the water habitability of the soil and deliver habitat for plant roots and soil organisms (Carter 2002; Meng *et al.*, 2014) Consequently, soils with higher organic matter are very fertile and highly advantageous for better or more favourable tree growth (Vahdati *et al.*, 2017). According to Bauer & Black (1994), the biomass production rate of plants is closely related to organic matter; therefore, plants should obtain more organic matter to increase their biomass production rate. Sirlluck *et al.*, (2021) revealed that organic matter was strongly related to pH and phosphorus, clarifying that the diversity and distribution of forest tree species is not only driven or influenced by organic matter content but that pH and phosphorus are important soil characteristics that participate in plant growth. In an earlier investigation in a tropical forest in Ben En National Park, Vietnam, it was stated that multiplication in organic matter may increase Phosphorus and pH, thus enriching species variation and plant distribution in the region (Hoang *et al.,* 2011). A higher ratio of sand to the soil has been reported to reduce water habitability, which can provoke or catalyse water stress in trees (Arangun *et al.,* 1982; Toledo *et al.,* 2012; Zhang *et al.,* 2013), and acidity levels have been recorded to drive forest tree species distribution and are associated with slopes and elevations in tropical lowland forests (Nguyen *et al.,* 2015; Vahdati *et al.,* 2017). Trees that flourish in clay soils have been reported to have a well-organized root system and are less prone to periods of lower water stress as an outcome of the soil's considerable water-holding capacities. Trees with roots extending far down from the top surface in sandy soil possess a significant probability of existing as they acclimate to lessen drought stress (Wessel 1971). Thus, a deep root structure encourages plants to acclimate and tolerate exceptional drought conditions, like being away from water sources or in areas with narrow soil moisture. Soil moisture has been reported to dramatically alter the arrangement of tree growth in dry or dehydrated areas (Fu *et al.,* 2004; Yoshifuji *et al.,* 2006; Asanok & Marod, 2016; Tilk *et al.,* 2017). In moderately moist and humid soils, the relationship between species growth and the gradient of acidity has been stated by several researchers (Oland *et al.,* 1998; Ewald, 1999; Coker, 2000; Ewald, 2000; Philips *et al.,* 2002; Crowley *et al.,* 2003; Taleshi, 2004). It has been reported that soil texture and cation exchange control the growth of plant species by influencing moisture availability, aeration, and root distribution. Soil texture is the greatest basic physical characteristic of soil, driving the exchange and uptake of water, nutrients and oxygen (Schoenholtz *et al.,* 2000) and controlling the growth and distribution of vegetation (Fischer and Binkley, 2000). Organic carbon and nitrogen have been reported to be effective variables in plant species differentiation (Zahedi Amiri & Mohammadi Limayee, 2002; Salehi *et al.,* 2005). Soil nutrients like nitrogen, potassium, phosphorus, calcium, and magnesium have been reported to be connected with the richness and distribution of plant species in tropical forests (Paulo *et al.,* 2007; Zhang *et al.,* 2013; Tilk *et al.,* 2017). In our study, PCA revealed perceptible variables of soil characteristics in our study zones. Because these procedures are highly accurate and have a distinct ability, they can be used to analyse habitats and discover operative environmental components. Analysis of ecological data using multivariate or ordination methods allows for easy apprehension of the composite association amid plant and environmental gradients.

Conclusion

Our MaxEnt model identified six climate integrants that drive or influence forest tree species diversity and distribution across Cross River State, Nigeria. These are ‘isothermally (BIO 3)’, ‘temperature seasonality (BIO 4)’, ‘annual temperature range (BIO 7)’, ‘annual precipitation

(BIO 12)', 'wettest quarter precipitation (BIO 16)', and 'driest quarter precipitation (BIO 17)'. Our PCA results revealed that different sets of soil integrants in the northern, central and southern zones of Cross River State, Nigeria, influenced forest tree species diversity and distribution. Seven fundamental soil integrants sustained the growth, diversity and distribution of forest tree species in the northern zone; they include iron, Available Phosphorus, manganese, Exchangeable cation, silicon, Hydrogen ions and organic matter. In the central zone, ten fundamental soil integrants have been identified. They include zinc, organic matter, Exchangeable cations, Total Nitrogen, Sodium, boron, clay, soil pH, Exchangeable acids and silicon. In the southern zone, nine soil integrants drive the growth, diversity and distribution of forest tree species; these include sand, silt, Organic Carbon, Magnesium, Hydrogen ion, Calcium, Cation exchange capacity, Potassium and clay. Our in-depth component-based evaluation is anticipated to provide unbiased awareness of the ecological niches of forest tree species diversity and distribution. Our findings could be applied or exploited as rudimentary details for managing forest and ecosystem conservation generally and characteristically for forest conservation across Cross River State, Nigeria

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