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Modeling the Suitability Index of Selected Conifers on Mambilla Plateau Taraba State, Nigeria: Implication on Planted Forest

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Abstract The Mambilla Plateau is a semi temperate highland region found within the broader tropical savannah of northeast Nigeria which supported the growing of cold tolerant fruits such as apple and pears was explored to determine its suitability for growing of cold tolerant conifers in contrasts to the surrounding tropical ecosystems. The authors conducted an exploratory work using both modeling and seedling germination tests to determine the feasibility of survival and suitability of conifers on the Mambilla plateau. The work investigated growth factors such as water availability (maximum average rainfall for optimum growth, minimum rainfall for survival) and temperature (maximum average temperature for optimum growth and minimum temperature required for survival). A climate envelope model (CEM) of species distribution and pre validated germination test were conducted on the selected species in Diva GIS software and on the field respectively to identify the potentially suitable sites on the plateau. Of the four conifer species under investigation *Pinus ponderosa* of Pacific Northwest, USA origin and *Pinus caribaea* of Nicaragua *var. honduresis* origin were found to be potentially suitable to the Mambilla Plateau environment. However, relatively robust and longer field trials were suggested on the two species before any conclusive action is taken.
Keywords *Species Distribution Model; Prediction; Biogeoclimatic Ecosystems; Suitability Index*

1. Introduction

Most of the studies conducted in the past on tree trials for afforestration programme in developing countries especially in Africa had been on trial and errors basis with little or no preliminary studies on the planting sites (Zobel et al., 1987), and the determination of species suitabilty index. Apart from Southern and East Africa where cold tolerants conifer species such as *Pinus radiata, Pinus patula, Pseudotsuga menziesii* have been widely grown, trials of cold tolerant tree species in Nigeria were rare and poorly documented (McComb and Johnson, 1969; FAO, 2013).

The most common strategy to estimate the actual or potential geographic distribution of species is to characterize the environmental conditions that are suitable for the species and then identify where suitable environments are distributed in space (Pearson, 2007). There are two basic approaches to species distribution model (SDM): the mechanistic model and correlative model. Climate envelope model is a subset of (SDM) and has been used to model or predict the distribution of species under current, future and past climatic conditions by inferring a species environmental requirement from localities where it is currently known (Magness, Huettmann et al., 2008), Common environmental variables use in the modeling are: climate, land cover and topography (Hijmans et al., 2006; Watling et al., 2012).

The Mambilla Plateau is located between latitude 6.3212^0 and 7.5523^0 N, and longitude 10.2723^0 and 11.5345^0 E (Decimal Degree-DD) and covering about 3,765 km² and adjoining land of 1250 km² which constituted Sardauna local government administrative unit of Taraba state Nigeria. Mambilla Plateau is a highland region which is the northern continuation of the Bamenda highland of Cameroun. It is bounded on the north east by Gashaka local Government, in the North West by Kurmi Local Government and south by the Republic of Cameroun.

The climate of the plateau is cold especially in the low and high mountains regions of Nguroje and Kakara in the north central and pockets of Dorofi in the south east and Chappal Waddi in the Far East ends. The climate has oftentimes been described as a temperate island in the “ocean” of the tropics. With a mean annual temperature of 18-19°C and minimum as low as 10-11°C in January, maximum temperature rarely exceeds 25°C, the plateau is the coldest in Nigeria and one of the coldest regions in tropical Africa (Adebayo and Umar, 2005; Salako, 2011). The plateau receives over 1800mm of rainfall annually, which is evenly distributed with a very short dry period between December and January. Figure 1 shows five major biogeoclimatic ecosystem zones on Mambilla plateau and the adjoining land: Grass eucalyptus cold high (GCHM), Grass cypress cool mountain (GCM), Escarpment stream valley forest (EVF) Montane forest (MF) and Humid lowland forest (HLF). Given the unique physico climatic conditions of the Mambilla plateau, the following are the objectives of this work.

1) To identify conifers species that are suitable for the Mambilla Plateau using species distribution modeling approach,
2) To draw a predicted suitability map for the species on the plateau;
3) To provide the basis for species field trial on the plateau for planted forest.

2. Materials and Methods

2.1. Determination of Species Ecological Niches and Suitability Index

To determine the ecological niche of selected species across the Biogeoclimatic ecosystem zones on the plateau, 40 presence points were randomly selected at 5 per 100km × 100km grid for each of the four candidate species from Global Biodiversity Inventory Facility (GBIF). Presence points are the geographic coordinates of natural habitat where the species are found to occur. The two climatic variables used to run the envelope in DIVA GIS are mean annual temperature and total annual precipitation (Watling et al., 2012).

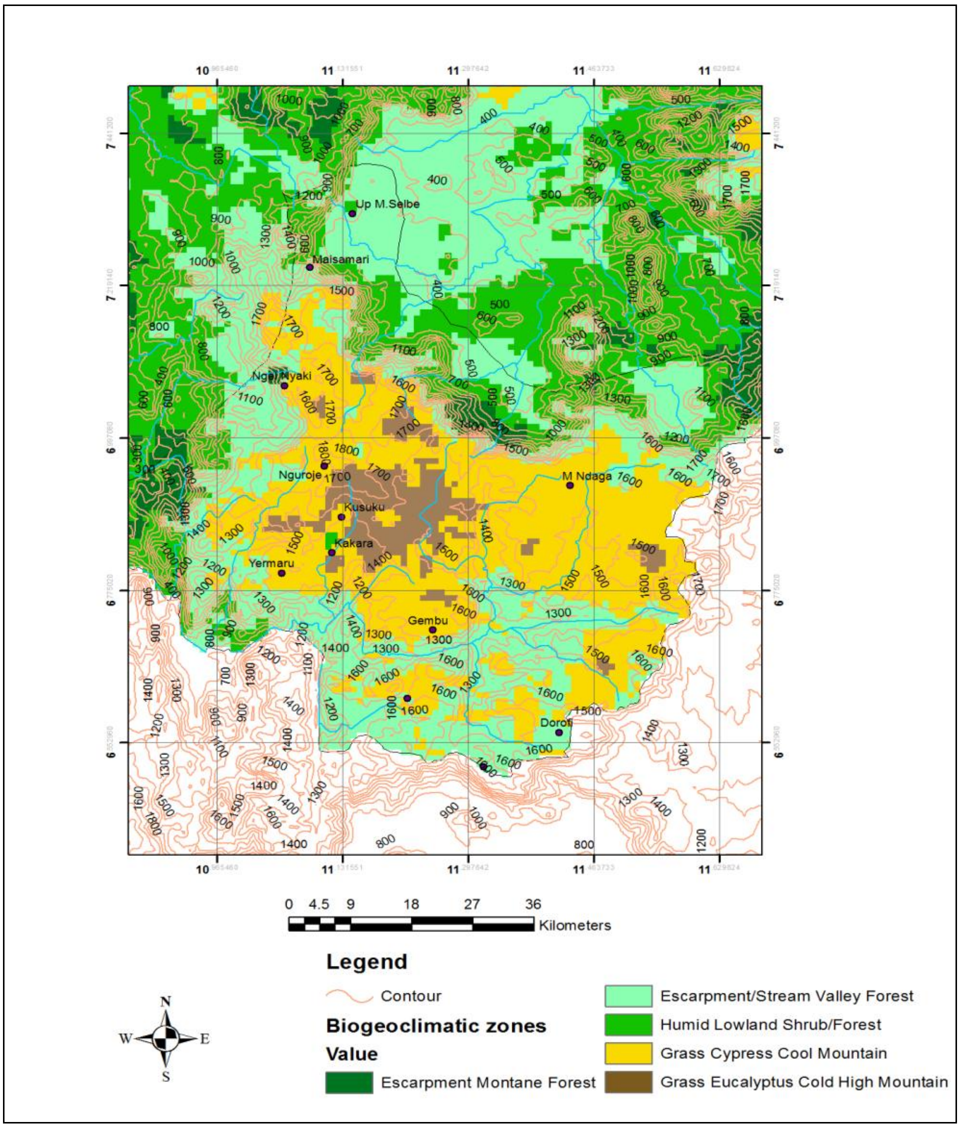

Figure 1: *Mambilla Plateau Biogeoclimatic Ecosystems Zones*
Source: Salako 2015 Unpublished PhD Seminar

Also 40 random background points across all the biogeoclimatic zones of the study area were obtained using GPS; these are the random sampling of points in the study area where the species are yet to be present, also referred to as ―pseudo absence (Watlings, 2012). These points help to describe the background environmental conditions especially the climatic and vegetation of the study area and helps in the model performances as it defines the model domains or the geographical area in which the model is being constructed (Phillips et al., 2009). Drawing pseudo absence or background data from a distance far away from the presence points has made it much easier for the model to differentiate suitable areas from unsuitable areas (VanDerWal et al., 2009).

These points were first prepared in Microsoft Excel software (Hijmans and Elith, 2013) and subsequently converted to shape file format in ArcGIS 10.2 version before they were imported to Diva GIS environments to determine the ecological niche of each of the species using a climate envelope model (CEM) - BIOCLIM algorithms. "The BIOCLIM algorithm computes the similarity of a location by comparing the values of environmental variables at any location to a percentile distribution of the values at known locations of occurrence training site" (Hijmans and Elith, 2013)

Having determined the ecological niches of the identified species from which four species were taken as candidates; three native to the Pacific North West (PNW), *Pinus ponderosa*, *Pseudotsuga menziesii, Thuja plicata* and one from outside the region, native to the Caribbean, *Pinus caribaea*, The four candidates species were further subject to prediction to determine their survival and suitability on Mambilla plateau using both BIOCLIM and MAXENT algorithms. Elith et al. (2009) defined Maximum Entropy (MAXENT) as an algorithm for climate envelope modeling that calculates the probability of occurrence of a species as a function of environmental (climate) conditions where the species occurs relative to background conditions in the area of interest. In running suitability index using Bioclim in DIVA GIS and Maxent for prediction of potential suitable sites, six bioclimatic variables were taken into consideration: total annual rainfall, mean annual temperature, maximum temperature of warmest months, minimum temperature of coldest months, rainfall of the driest months, and rainfall of the wettest months. These variables represent the absolute, average and range of climatic variables (Scheldeman and Zonneveld, 2010) and of significant implication on plant physiology (Hijmans et al., 2006).

The study area land cover grid (GLC, 2000) was used as output file for prediction. The area under the receiver-operator characteristic curve otherwise called area under curve (AUC) was used to evaluate the performance of the model. AUC is a threshold- independent metric ranging from 0—1, the closer the model AUC values to 1 the higher the model ability to predict suitability at species known presence (Watlings et al., 2012) and remain the widely used for model performance (Manel et al., 2001).

In order to assess the validity of the model predictions and determine the survival of the species on the field, a germination test was carried out on the four species. The germination test was conducted in July and August 2014. The Seed of ponderosa pines, Douglas fir and western red cedar are of Washington and Oregon origins and were acquired from Lawyer Nursery firms, WA United States, while Caribbean pine of Honduras origin was obtained from Ministry of Agriculture and Natural Resources (Forestry Department) Kaduna, Nigeria. 10 polythene bags containing potted soil were prepared for each species. Though species such as Douglas fir and western red cedar require cold stratification before planting (Capo-Arteaga et al 1991 Robbins and Ditlevsen, 2004), this however could not be done effectively due to insufficient power supply needed for 2-3 months cold stratification, however, efforts were made to wrap the seeds and put inside ice block which were changed in every 2 days for 1 month as an alternatives, meanwhile all seeds were soaked in water for 48 hours at temperature between 20 and 25°c and drained before sowing (Luna et al., 2009). 4-5 seeds of each species were sown into the bags and keep moist throughout the tests to prevent wilting. Monitoring was done twice daily: early in the morning (0700hrs) and in the evening (1700hrs).

3. Results and Discussions

3.1. Species Ecological Niche Determination & Suitability Index across Biogeoclimatic Zones

The ecological niches of the three species (*Pinus caribaea, Pinus ponderosa and Pseudotsuga menziesii)* under study were found to conceptually fall under the Mambilla Plateau biogeoclimatic ecosystems environment especially when assessed based on annual mean temperatures, minimum temperature of coldest month, maximum temperature of warmest month and total rainfall. The AUC for the model was very high ranging from 0.991 for pinus caribaea, 0.998 for ponderosa and to 0.999 for thuja plicata and menziesii.

BIOCLIM suitability index measurement ranges from 0 (not suitable) to 40 (excellent suitability) while MAXENT measures from 0 (not suitable) to 1 (very highly suitable). There are variations in the suitability index after prediction among the four species. Pinus caribaea on Maxent shows a broader and high suitability index as most part of the study area are potentially suitable, excellent suitability index 0.7908-1.00 in MAXENT was found in the cool and wet area of the low mountains ecosystem

(GCM) in the north, central and south parts (Figure 7), however this decreases significantly to (5-10 percentile) in Bioclim in the cold high mountains regions (GCHM) and not suitable at the coldest spot on the plateau (Figure 6).

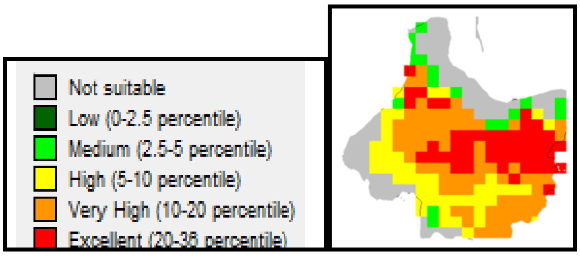

Figure 2: *Bioclim for Pinus ponderosa*

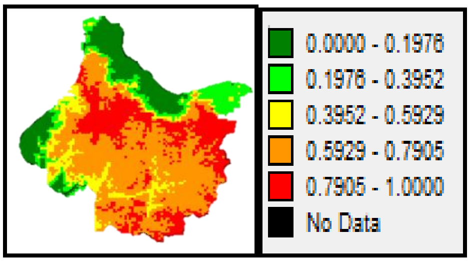

Figure 3: *Maxent for Pinus ponderosa*

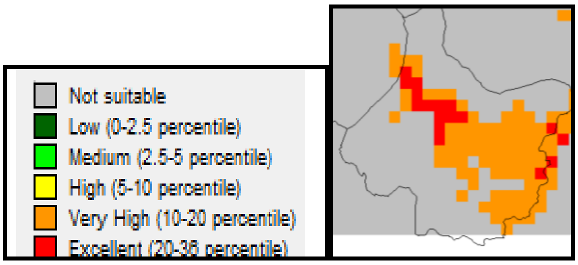

Figure 4: *Bioclim Pseudotsuga menziesii*

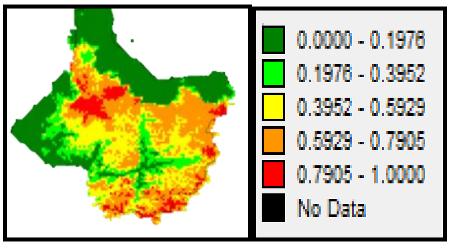

Figure 5: *Maxent for Pseudotsuga menziesii*

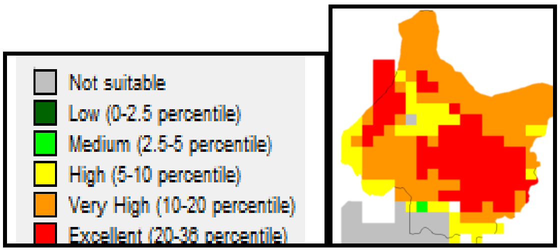

Figure 6: *Bioclim for Pinus caribaea*

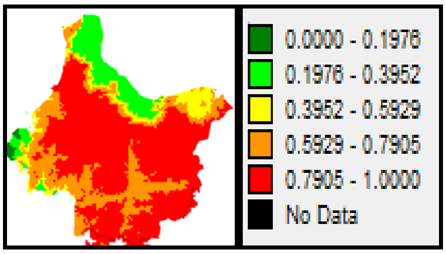

Figure 7: *Maxent for pinus caribaea*

Figures 2-7: *Bioclim and Maxent Suitability Index*

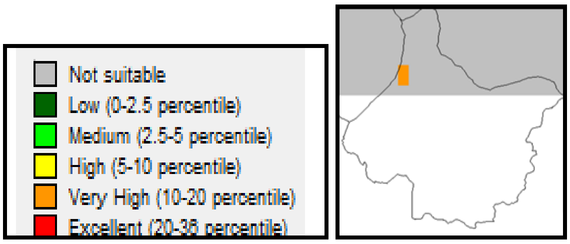

Figure 8: *Bioclim for Thuja plicata*

Caribbean pines thrive in rugged terrain but could grow in area as low as 10m (coastal plain) to area of high elevations of over 1000m with rainfall events of 1000mm-1800mm/year with understory consists of grasses and shrubs (Farjon and Styles, 1997; Dvorak et al., 2000). This assertion confirms the suitability of *Pinus caribaea* across different physiographic region on the plateau. However, frost and severe cold could hamper the growth of the tree (Dvorak et al., 2000) and this could be the reason while the suitability index of this species decreases in the colder part of the plateau.

Pinus ponderosa also has high suitability index in the cool and wet mountain (GCM) and cold and wet high mountains regions (GCHM) but unlike *Pinus caribaea*, both BIOCLIM and MAXENT predicted very poor and non-suitability values in the lower elevations especially in the Humid and irregular plains and escarpment regions (EVF) in the north east and south west region (See Figure 2 and 3).

Pinus ponderosa prediction of very high suitability index in the rugged terrain/mountains on the plateau supported the habitat description of Ponderosa pine as being a tree generally found in mountainous topography (Kuchler, 1969, Laacke 1990) and associated with grasslands from valley to Montane and tolerant of hot and dry conditions as well.

Figures (2 and 3) show a potentially excellent suitability index for *Pseudotsuga menziesii* in both MAXENT and BIOCLIM but restricted to colder regions of cold high mountains (GCHM) and high index in western sections of cooler low mountains region but with high rainfall (GCM). However, over 60% (2,280km^2) of the plateau was predicted as unsuitable for Pseudotsuga menziesii in BIOCLIM while it was about 40% (1140km^2) in MAXENT with another 25% (950km^2) being marginally suitable.

The distribution of Douglas fir (*Pseudotsuga menziesii*) appeared to be more influenced by temperature distribution and topography(Herman and Lavender 1999) rather than the rainfall on the plateau as excellent index was found on cold and wet high mountains (Figures 4 and 5) of (GCHM) and good index on the low mountains (GCM) on the east sides but poor on hot and humid forest (HLF) zone where though the rainfall is moderately high (1500mm) however, summer maximum temperatures reaches between 28°C and 30°C especially on the north east and extreme south west. This affirms the positions of Dirr (1997) and Brickell and Marc-Cathey (2004) that a continuous summer temperature of 86°F/30°C may not be suitable or ideal climate for *Pseudotsuga menziesii*.

Thuja plicata suitability index was very poor as over 98% of the study area was designated as not suitable however (Figure 8); a tiny potential suitable spot was found but restricted to cold highland mountains region on the plateau. Thuja plicata is a species predominantly well established in sub montane cool temperate climate, require much colder temperature and tolerate wide edaphic range as long as there is sufficient moisture (Meidinger et al., 1991).

The choice of *Thuja plicata* as candidate species in this study despite its narrow ecological niche and poor suitability index, is to maximally explore every part on the plateau at both climatic extremes-coldest and hottest. The suitability index of this species has clearly indicated that a few pockets in the coldest and wet regions on the plateau could be potentially planted with this species. Table 1 shows the potential distribution of the species across the biogeoclimatic zones as predicted by the model.

Table 1: *Summary of Potential Sites on Mambilla Plateau for the Conifers Species*

Species	Sites /Biogeoclimatic Zones	Remarks
Caribbean pine	Gembu, Maisamari, Mayo Ndaga Kan Iyaka (GCM and EVF zones)	Larger area are highly suitable for caribbean pine require cool temperature (Annual mean of 21^{0}C) and at least annual total rainfall of 1600mm
Ponderosa pine	Nguroje, Dorofi , Kakara (GCHM zone)	Colder temperature Annual mean temperature of 18^{0}C
Douglas Fir	Kakara, Kusuku (GCHM zone)	Colder temperature and high rainfall are required for Douglas fir
Western red cedar	Gurugu (marginal) (GCHM zone)	Required very cold temperature MAT of <16^{0}C and high rainfall very marginal site

A pre validated assessment of the model was done by carrying out the seed germination test. From the germination test, *Pinus ponderosa* and *Pinus caribaea* were able to germinate after 10 days without cold stratification (Luna et al., 2009) while Douglas fir seed shows sign of germination after 30 days but failed to sprout. *Thuja plicata* (Western red cedar) did not show any signs of germination. The germination rates of both pines were 70%. However, the preliminary finding during germination test shows that seed requiring cold stratification faces lot of challenges in Africa even if suitable climatic condition is found, the problems of refrigeration of seeds for a long time is hampered by erratic supply of power.

4. Conclusion

Species distribution model has been a useful tool in understanding the relationship between species habitat and the governing environmental variables which has assisted greatly in making an informed decision about species performances and behavior even in a poorly understood system and form the basis for field studies (Range-Illodi et al., 2011)

In this study the combination of physiography and climate were strong variables identified to have influenced the potential distribution and suitability of the species on the plateau however, variation in temperatures as patterned along the relief being the most defining factor. Given the results of germination test and suitability index map, *Pinus caribaea, Pinus ponderosa* and perhaps *Pseudotsuga menziesii* are suggested for further field trials on the plateau. Two Biogeoclimatic ecosystem zones (GCHM and GCM) are found to be potentially suitable sites for these species. This result should however be treated as indicator and not the actual performance of the species on the sites. A long term and detail field experiment or species trial is currently being undertaken by the leading author to further validate the results of this model. However, it has served as useful guide in pre selection processes for field trial.

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