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Projecting the impacts of climate change on tree biomass in Arabuko-Sokoke Forest, Kenya

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ABSTRACT

Scientific concerns regarding tropical deforestation and global climate change have prompted efforts towards quantification of forests as terrestrial carbon stores. The Arabuko-Sokoke forest ecosystem within Kilifi County is faced with forest degrading pressures from natural and community livelihood related drivers. Very limited studies have been done in this regard and this paper seeks to project how climate change will impact on tree biomass through empirical research by using Maximum Entropy (MaxEnt) Model. The prediction model based on RCP4.5 and 8.5 indicated that MaxEnt model can be used to predict geographical distribution of brachystegia and mixed forest at 2050 and 2070 (Area under Curve (AUC) = 0.80-0.90), while cynometra forest had a poor model fit (AUC=0.60-0.70). The jack knife test indicated that variables associated with annual trends, seasonality and extremities of temperature and rainfall parameters contributed to the all predictive model in this study. The study recommended that; the forest manager develops strategies to mitigate on shifting and fundamental niche reduction for key species. Communities are advised to diversify their sources of livelihoods. Carbon accounting systems and Greenhouse Gas (GHG) systems should consider impacts of climate change on tree biomass in Arabuko-Sokoke Forest.

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1. Introduction

Forests are a source of ecosystem goods and services; however, it is facing high levels of degrading activities due to increasing human population. Apart from reduction in ecological and social –economic functions of forests, forest losses leads to emission of greenhouse gases such as carbon dioxide into the atmosphere and this enhances climate change (Fujisaka *et al.*, 1998; Pielke *et al.*, 2002; Foley *et al.*, 2007; Hoscilo, 2014).

Scientific concerns regarding tropical deforestation and global climate change have motivated ongoing efforts to quantify the role of forests as terrestrial carbon store (Glenday, 2008). The need to quantify the forest carbon have seen a suite of techniques ranging from those that utilize forest inventory data to those methodologies that combines field data with remote sensing technologies. Despite the array of approaches the effects of climate on tropical forest carbon stocks remain uncertain. In particular, the application of process-based dynamic global vegetation models has led to contrasting conclusions regarding the potential impact of climate change on tropical forest carbon storage (Vieilledent *et al.*, 2016).

Recent studies (Glenday, 2006; Devaranavadi *et al.*, 2013; Chave, 2014; Poorter, 2015) have underlined the importance of climatic variables in determining tree height and biomass in tropical forests. The question of knowing whether tropical forests are likely to compensate for anthropogenic carbon dioxide emissions through a strong positive biomass response to climate change remains unanswered (Vieilledent *et al.*, 2016). The possible climatic effects on forest could range from limiting internal growth process such as less growth in maximal diameter and heights of the trees to limiting environmental conditions. Because these traits determine tree and forest biomass (Cox *et al.*, 2013; Chave, 2014; Vieilledent *et al.*, 2016) climate change should significantly impact forest carbon storage as well as the socio-economic wellbeing (Opijah *et al.*, 2017) of forest adjacent communities. The ability to predict how that will happen is therefore necessary, simpler correlative methods could offer rapid and robust

alternatives for the projection of the effects of climate change on tropical forest carbon storage (Vieilledent *et al.*, 2016). Whereas the predicted impacts of climate change on forest ecosystems are varied (IPCC, 2010), Kenya's forestry sector is vulnerable to climate change and its potential effects on the composition, growth rates, regenerative capacity (Stiebert *et al.*, 2012) has not been precisely documented. The vulnerability is higher for forest ecosystems that borders the oceans and seas like Arabuko-Sokoke because of the predicted sea level rise (Opere *et al.*, 2017, IPCC, 2014b). The Arabuko-Sokoke forest ecosystem despite facing pressure from forest degrading activities supports a wide range of ecological and livelihood functions (Glenday, 2008, Oyugi *et al.*, 2008; Musyoki *et al.*, 2016). However, very limited research (Mutangah, 1992; Glenday, 2008; Oyugi *et al.*, 2008; Musyoki *et al.*, 2016) has been undertaken on the ecosystem and even much less focus has been given to how climate change will impact on tree biomass and vegetation dynamics. This situation coupled with the multiplicity of role forest plays i.e. support to local livelihood, store of genetic diversity, habitat for threatened birds and animal species among others, creates a need for better understanding impact of climate change on forest tree biomass by climate change.

2. Materials and Methods

The study was conducted in Arabuko-Sokoke forest located within Kenya's Coast strip of Kilifi County (**Figure 1**). The forest reserves lies within a geographical bounds of 3°20' South and 39°50' East (Glenday 2008). The Arabuko-Sokoke forest has an area of 41,600 ha with about 5,935 ha designated as nature reserve. The north eastern side of the forest borders the shores of Mida Creek at sea level. Elevation increases westward, with a steep Climb from the eastern coastal plain (0–45 m above Sea level) to a plateau (60–135 m) in the central and western parts of the forest reaching a peak of 210 m in the southwest. The forest has three distinct and well described vegetation types (Mutangah, 1992; Muchiri and Kiriinya 2001; Glenday, 2008; Musyoki *et al.*, 2016) as influenced by soil types, rainfall regimes and altitudinal variations. The vegetation types are briefly described below;

1. **Mixed forest** – This is a dense vegetation type, which extends to about 7,000 ha on the wetter coastal sands to the eastern side of the forest. It has a diverse flora, which includes *Azelia quanzensis*, *Hymenea verrucosum*, *Combretum schumanii*, *Manilkara sansibarensis* and *Encephalartos hilderbrandtii*
2. **Brachystegia forest** – This is a more open forest covering an area of about 7,700 ha, dominated by *Brachystegia speciformis* on the drier and infertile white sands through the centre of the forest
3. **Cynometra forest** – This is a dense forest or thicket on the northwest side of the forest covering about 23,500 ha on the red Magharini sands towards the western side of the forest. It is dominated by *Cynometra webberi*, *Manilkara sulcata*, and *Euphorbia candelabrum*, but in reducing numbers. *Brachylaena huillensis* also used to be abundant in this zone, but its numbers have been severely reduced by extraction

The forests is a designated Important Bird Areas (IBA's) with endemic bird species numbering about 270 species including six which are globally threatened and three near threatened species (Fitzgibbon *et al.*, 1995; Muchiri and Kiriinya, 2001; Glenday, 2008; Matiku *et al.*, 2013, Musyoki *et al.*, 2013).

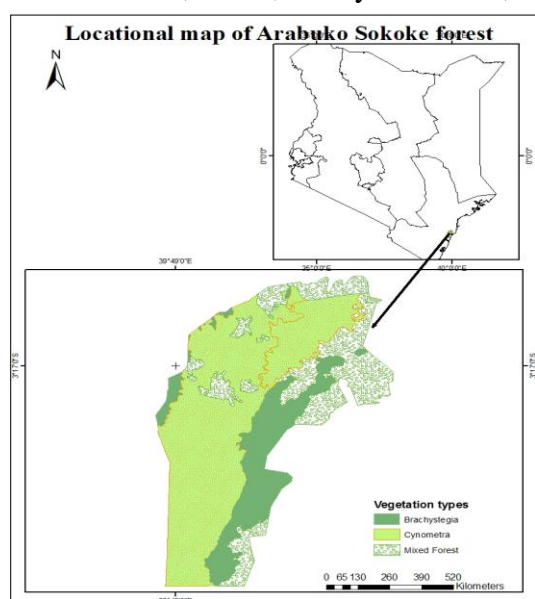


Figure 1: Map showing location and vegetation types in Arabuko-Sokoke forest

The local topography is fairly flat; the sandy coastal strip has influenced the soil types. The drier western ridge parts of the forest consist of leached red soils. The others parts has deep, band of white, infertile sandy soils. The eastern coastal plain has grey coloured pleistocene lagoonal sands and clays. While silt soils are found on the dry north western edges (Mutangah, 1992).

The rainfall regime varies across the elevation gradient with the eastern coastal edge receiving 1000–1100 mm/year and north western forest receives 600–900 mm/year. The mean annual temperature ranges from 21°C to 26°C with a mean daily temperature of 25°C. The humidity is generally high with little fluctuation throughout the year (Glenday, 2008).

While the towns on the eastern edge have more amenities to service the tourism industry along the Gede-Malindi coastal strip, most of the approximately 104,000 people surrounding the forest are small-scale farmers (Sinclair *et al.*, 2011). According to (Fitzgibbon *et al.*, 1995) 62.7% of household living adjacent to the forest, and 33.3% of households living within 2 km of the forest were engaged in hunting and trapping activities within the forest. This indicates a community that has high forest dependency as a source of their nutritional and livelihood needs.

2.1 Research design

Experimental research design was used in determining how climate change will impacts its distribution. A total of 21 permanent sample plots (PSPs) distributed randomly within the three vegetation types namely; **mixed** forest (10 plots), **brachystegia** forest (6 plots) and **cynometra** forest (5 plots) were the source of tree data (**Figure 2**). These PSPs measuring 50 m x 50 m were established in 1988 and 1990 when the first tree measurement were done. The second and third tree assessments were done in 2004 and 2015 respectively. The information that was captured at the plot is the species type, tree diameter at breast height (DBH) and plot coordinates.

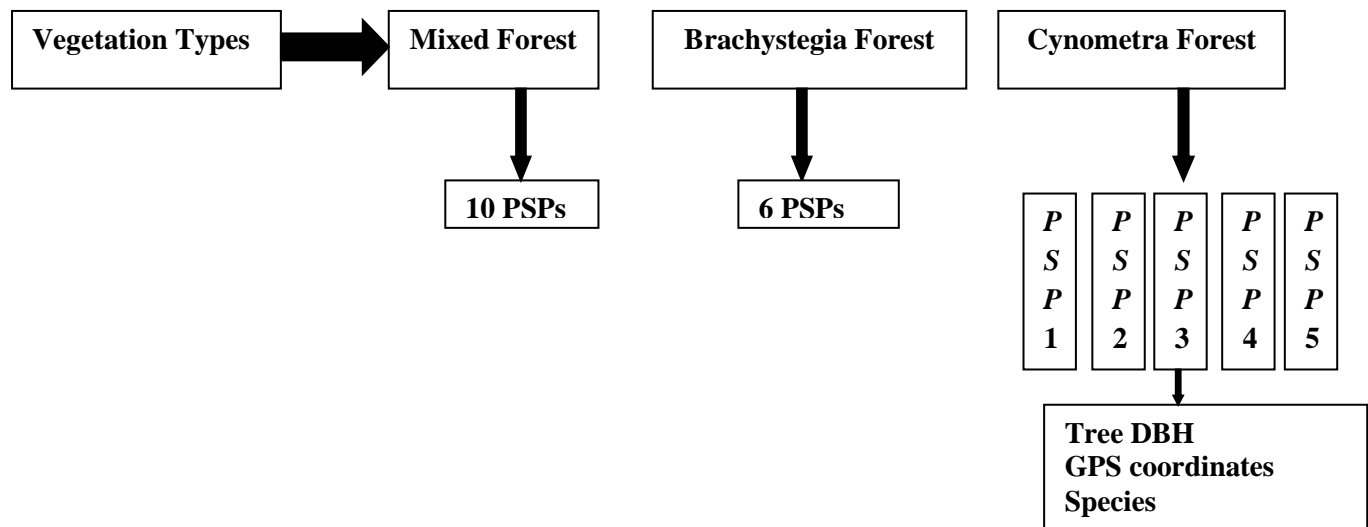


Figure 2: Research design of plot and tree data collection in Arabuko Sokoke forest reserve

2.2 Data Collection

The future environmental data were obtained from Worldclim-Global climate data (Hijmans *et al.*, 2005; Climate, 2012; Climate, 2013) together with 19 derived bioclimatic variables (**Table 1**). The resolution of the data was 1 Km square and was based CMIP5 scenarios which were used in the development of the fifth IPCC report. The data for RCP4.5 and RCP8.5 at 2050 and 2070 were downloaded from CNRM-CM which was developed jointly by CNRM-GAME (Centre National de Recherches Me'te'orologiques—Groupe d'e'tudes de

l'Atmosphe're Me'te'orologique) and Cerfacs (Centre Europe'en de Recherche et de Formation Avance'e) in order to contribute to phase 5 of the Coupled Model Intercomparison Project (CMIP and it provided data freely for non-commercial uses. The RCP4.5 represents the current directions of climate policy and technological interventions towards managing climate change, whereas RCP8.5 presents the scenario based on no climate policy and other interventions in place with high population levels

Table 1: Bioclimatic Variables (Hijmans *et al.*, 2005)

Code	Description	Code	Description
BIO1	Annual Mean Temperature	BIO10	Mean Temperature of Warmest Quarter
BIO2	Mean Diurnal Range (Mean of monthly (max – min)temps	BIO11	Mean Temperature of Coldest Quarter
BIO3	Isothermality(BIO2/BIO7)(* 100)	BIO12	Annual Precipitation
BIO4	Temperature Seasonality (standard deviation *100)	BIO13	Precipitation of Wettest Month
BIO5	Max Temperature of Warmest Month	BIO14	Precipitation of Driest Month
BIO6	Min Temperature of Coldest Month	BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO7	Temperature Annual Range (BIO5-BIO6)	BIO16	Precipitation of Wettest Quarter
BIO8	Mean Temperature of Wettest Quarter	BIO17	Precipitation of Driest Quarter
BIO9	Mean Temperature of Driest Quarter	BIO18	Precipitation of Warmest Quarter
		BIO19	Precipitation of Coldest Quarter

Species occurrence data were derived from plot UTM coordinates. The BioClim layers from Worldclim-Global climate data were clipped into the spatial extent of Arabuko-Sokoke Forest (Map). These layers represented the current and future environmental conditions based on climate model for 2050 and 2070. The first MaxEnt model run was trained using of 75 % of the data will the remaining 25% of data was used for model validation. Some output files (**Figure 3**) were manipulated using ArcGIS and displayed in form of maps to depict suitable and unsuitable sites for the three vegetation types in Arabuko-Sokoke.

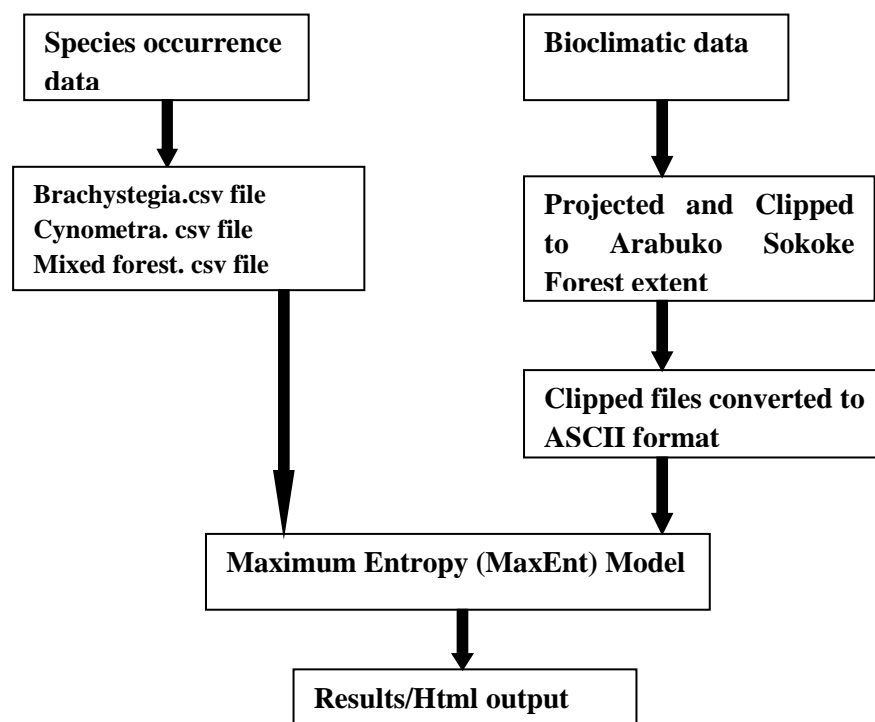


Figure 3: Schematic of modeling impacts of climate change in Arabuko-Sokoke forest

Collected data subjected to tests of normality and homogeneity of variance before being transformed where necessary. The MaxEnt model performance was assessed by using Area under the Relative Operating Characteristic (ROC). Where a value of 0.5 indicates the results could be random and confidence increases the nearer to 1. Additionally visual comparison of the maps was done between actual and predicted species distribution. Analysis of variable of contribution was used to test of environmental variable contribution, while the Jack knife tests was used to identify the most important variables by running a test for each variable in isolation and comparing it to all of the variables (Joshi, 2015).

3.0 RESULTS AND DISCUSSION

3.1 Impacts of climate change based on RCP 4.5 and RCP 8.5

3.1.1 Analysis of sensitivity and specificity based on RCP 4.5 and RCP 8.5

The significance of the (ROC) curve is quantified by the area under curve (AUC) and has values of predictive accuracy (Swets, 1988): 0.50-0.60 (fail), 0.60-0.70 (poor), 0.70-0.80 (fair), 0.80-0.90 (good), and 0.90-1.0 (excellent). The results in Table 2 indicates that the constructed models based on climate scenarios RCP4.5 and RCP8.5 for *brachystegia* and mixed forests have good predictive accuracy and therefore can be used to predict suitable distribution sites for brachystegia and mixed forests in Arabuko-Sokoke forest reserve. The study further shows (**Table 2**) that *cynometra* had poor predictive model and therefore its suitable sites cannot be predicted based on climate scenarios using MaxEnt model

Table 2: Summary of AUC results based on RCP4.5 and RCP8.5 at 2050 and 2070

Vegetation Type	Year	RCP 4.5		RCP 8.5	
		AUC(Training)	AUC(Test)	AUC(Training)	AUC(Test)
<i>Brachystegia</i>	2050	0.96	0.86	0.96	0.86
	2070	0.95	0.89	0.95	0.93
<i>Cynometra</i>	2050	0.87	0.5	0.93	0.55
	2070	0.92	0.58	0.91	0.65
<i>Mixed</i>	2050	0.93	0.86	0.95	0.9
	2070	0.96	0.87	0.97	0.95

The above observations are explained by the how climatic parameters correlate with tree biomass, where the biomass for *brachystegia* and mixed forests are impacted by climatic parameters, while poor relationship was noted for the *cynometra* forest. However, (Norby and Luo, 2004) study concludes that ecosystem responses to future climate change will involve multiple environmental factors, rather than just climate warming or increases in atmospheric CO₂ concentration and this may be the reason why *cynometra* forest was not modelled to a good level. It is also reasoned that when models perform poorly, the analyses were lacking significant variables to predict suitable habitats (Waters *et al.*, 2004) or relied on inconclusive field data (Hernandez *et al.*, 2006; Real *et al.*, 2006). An alternative interpretation might consider weak model performances as a clue to species traits and an early warning of a generalist's positive response to new habitats (Evangelista *et al.*, 2008). Additionally adaptations of trees to climate and resource gradients, coupled with disturbances and forest dynamics, create complex geographical patterns in forest assemblages and structures (Pan *et al.*, 2013). (Glenday, 2008) noted a section of Arabuko-Sokoke faced disturbances in the past and the *cynometra* forest was part of the forest affected and therefore it's postulated that its recovery process may have created a complex geographical pattern and therefore closer observation is recommended. Because understanding the interaction between species and its surrounding environmental variables are significant to predict the current and future species habitat distribution (Baldwin, 2009; Adhikari *et al.*, 2012)

The predictive MaxEnt models based on *brachystegia*, *cynometra*, and *mixed* forests

recorded higher AUC values in 2070 for RCP4.5 and 8.5 than in 2050 for RCP4.5 and RCP8.5; this is generally indicative that key variables associated with habitat suitability and species traits were successfully identified for the analyses (Boyce *et al.* 2002, McKenney and Pedlar 2003, Gibson *et al.* 2004) and captured by the constructed models.

3.2 Climate suitability maps generated from MaxEnt and Arc Gis based on RCP

The future species suitability zones were derived for RCP4.5 and RCP8.5 at 2050 and 2070, through MaxEnt model. The suitability ranges were; certainly (0.6-1.0), likely (0.45-0.60), possibly (0.30-0.45), unlikely (0.2-0.3) and rarely (0.00-0.17) and were mapped. The red colour indicates highly suitable areas while green colour depicts zones of unsuitability for *brachystegia* forest based on RCP4.5 at 2050 and 2070 (Figure 4). While the red colour indicates zones of unsuitability while green colour depicts highly suitable areas for *brachystegia* forest based on RCP8.5 at 2050 and 2070 (Figure 5). In the *cynometra* forest, the dark green colour shows areas of higher suitability while black colour indicates zones of unsuitability based on RCP 4.5 at 2050 and 2070 (Figure 6). The blue colour shows areas of higher suitability while orange colour indicates zones of unsuitability based on RCP8.5 in 2050 and 2070 in *cynometra* forest (Figure 7). The suitability maps for *mixed* forest based on RCP4.5 at 2050 and 2070 were depicted by shades of green for suitable area and purple for unsuitable areas (Figure 8). While based on RCP 8.5 at 2050 and 2070 red colour depicts suitable area and shades of grey for unsuitable areas respectively (Figure 9)

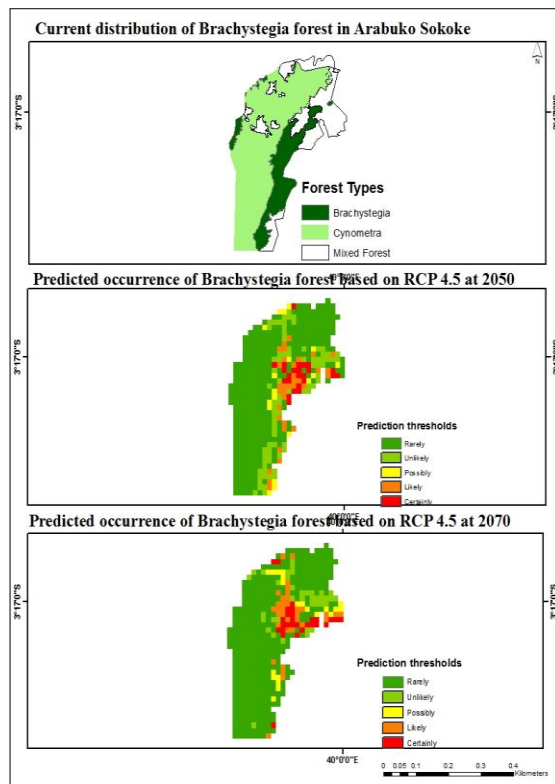


Figure 5: Climate suitability map for brachystegia forest based on current conditions and RCP4.5 at 2050 and 2070 in Arabuko-Sokoke forest reserve

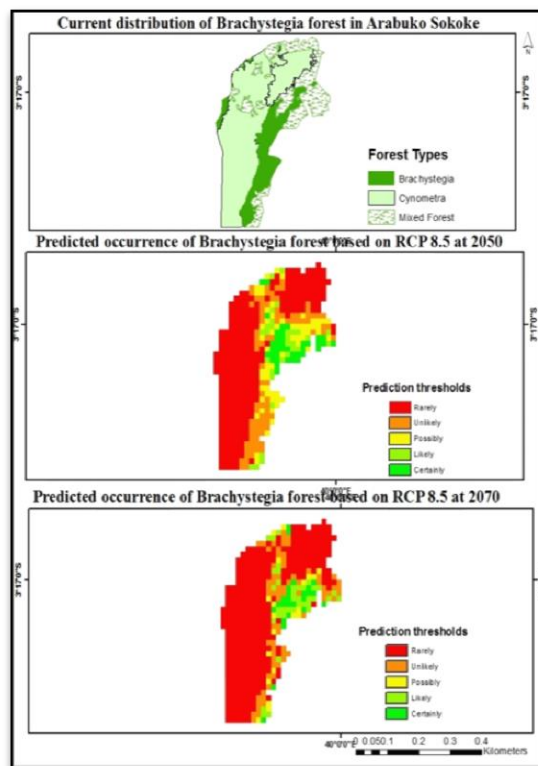


Figure 4: Climate suitability map for brachystegia forest based on current conditions RCP8.5 at 2050 and 2070 in Arabuko-Sokoke forest reserve

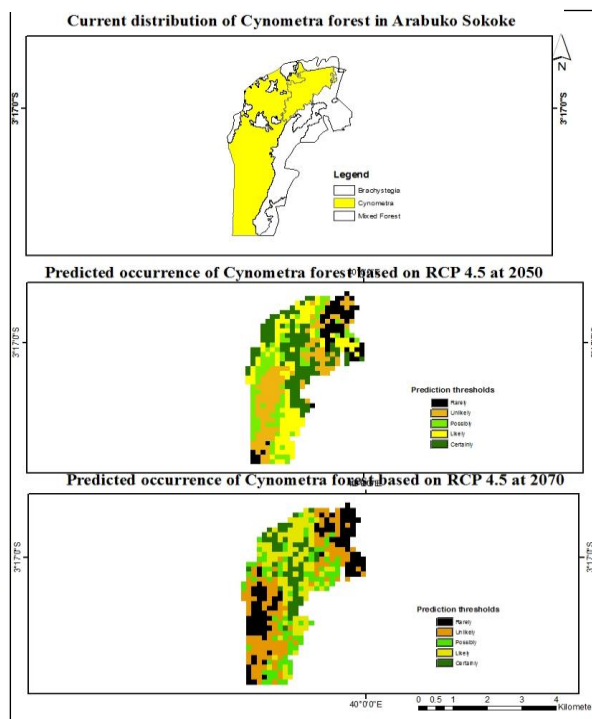


Figure 7: Climate suitability map for cynometra forest based on current conditions RCP4.5 at 2050 and 2070 in Arabuko-Sokoke forest reserve

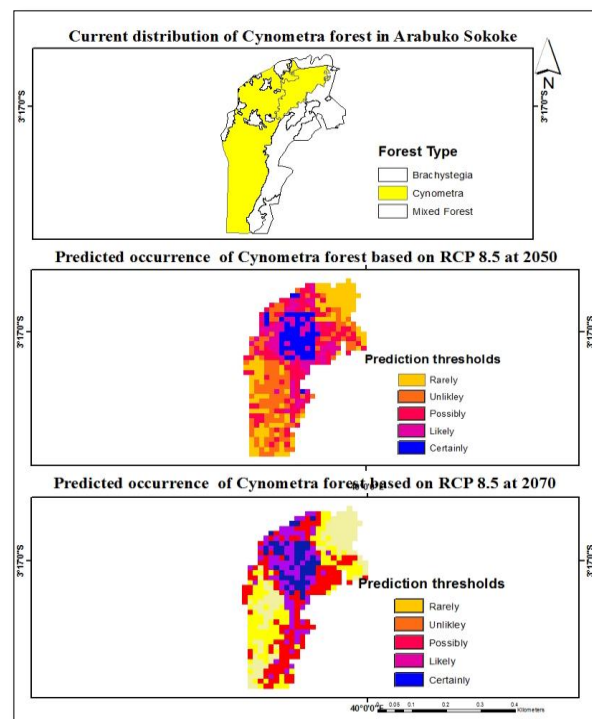


Figure 6: Climate suitability map for cynometra forest based on current conditions RCP8.5 at 2050 and 2070 in Arabuko-Sokoke forest reserve

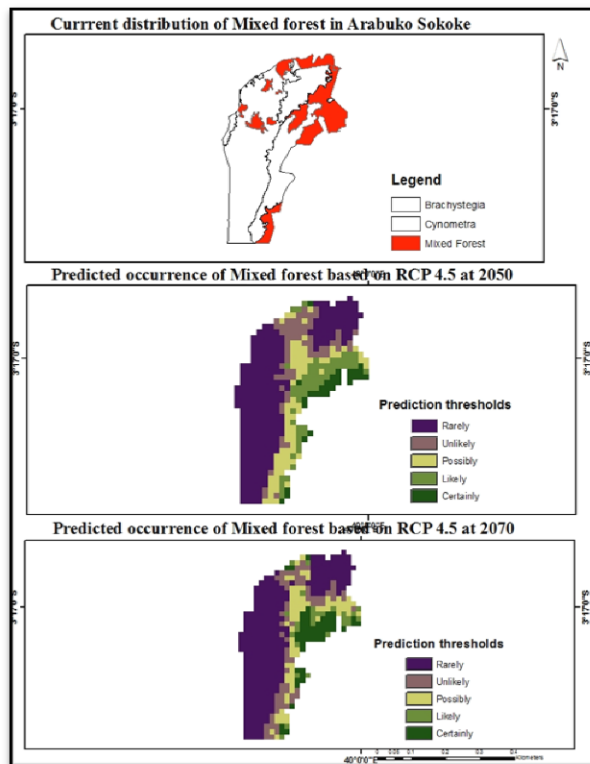


Figure 9: Climate suitability map for mixed forest based on current conditions, RCP4.5 at 2050 and 2070 in Arabuko-Sokoke forest reserve

The species suitability maps based on RCP4.5 at 2050 and 2070 indicates variation in species predicted occurrences. The *cynometra* forest suitability map shows that the area of occurrence will reduce, leaving the species to occur at the central part of the forest by 2070, similarly the mixed forest will record reduction in area of coverage and shifting of species to the eastern side of the forest and *brachystegia* will shift upwards and see reduction of areas. These results show that the climatic conditions will be unfavourable to Arabuko-Sokoke forest species range, pointing to observation of other studies. (Iverson and Prasad, 2001, Thompson *et al.*, 2009) suggested that some of the major considerations under the impact of climate change on floral biodiversity include changes in species distribution, increased extinction rate of species, changes in reproduction timings and in length of growing season for plants. In contrast the species occurrence and area under coverage will increase and shift for mixed and *cynometra* forests under RCP8.5 at

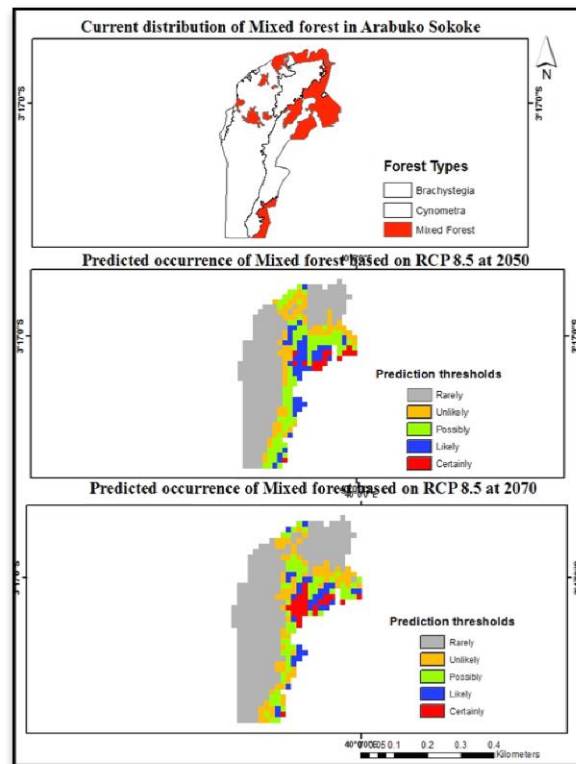


Figure 8: Climate suitability map for mixed forest based on current conditions, RCP8.5 respectively at 2050 and 2070 in Arabuko-Sokoke forest reserve

2050 and 2070, while *brachystegia* forest will experience shifting and reduction in area of occurrence. These results postulates that climate scenario based on RCP8.5 will be favourable to *cynometra* and *mixed* forest though possibly causing extinction of some species or reduction in suitable ecological conditions for some current species in Arabuko-Sokoke.

3.3 Jackknife test for variables based on RCP4.5 and RCP8.5

The result of the jackknife test of variable importance for *brachystegia*, *cynometra* and *mixed* forests indicates the predictive power of various bioclimatic variables (**Table 3**). For example the Mean Temperature of Wettest Quarter (Bio8) had the highest gain when used in isolation in 2050 and 2070, while Mean Diurnal Range (Mean of monthly (max temp - min temp) (Bio 2), decreases the gain the most when it is omitted in 2050 and Mean Temperature of Coldest Quarter (Bio 11), decreases the gain the most when it is omitted in 2070 (**Figure 11**)

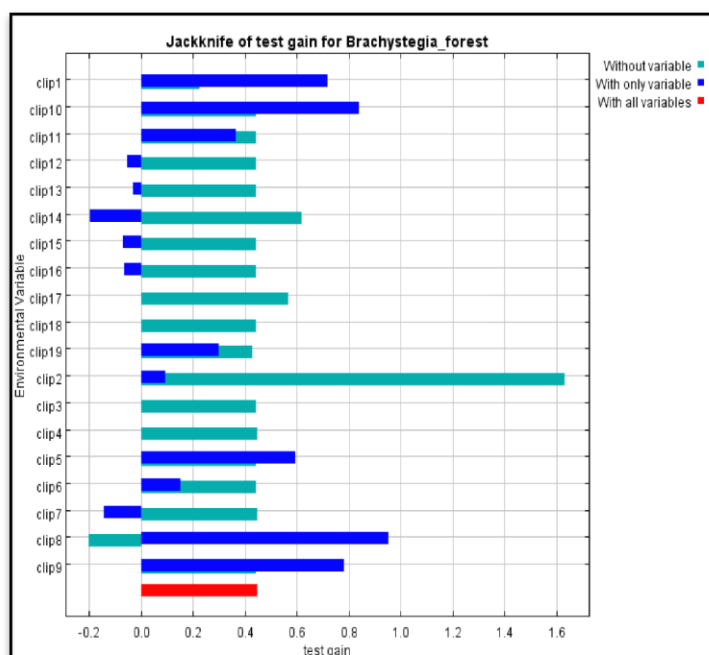


Figure 10: Predictive power of different bioclimatic variables based on the jackknife test for brachystegia forest based on RCP4.5 at 2050

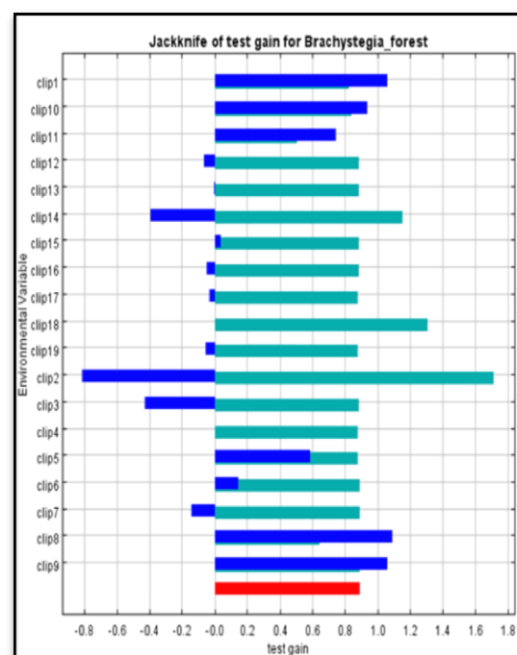


Figure 11: Predictive power of different bioclimatic variables based on the jackknife test for brachystegia forest based on RCP4.5 at 2070

Table 3: Summary of Predictive power of different bioclimatic variables based on the jackknife test for Arabuko-Sokoke

Vegetation Type	Year	RCP 4.5		RCP 8.5	
		Highest Gain	Highest Loss	Highest Gain	Highest Loss
<i>Brachystegia forest</i>	2050	Mean Temperature of Wettest Quarter (Bio8)	Mean Temperature of Wettest Quarter (Bio8)	Temperature of Wettest Quarter (Bio8)	Precipitation of Driest Month (Bio 14)
	2070	Mean Diurnal Range (Mean of monthly (max temp - min temp) (Bio 2)	Mean Temperature of Coldest Quarter (Bio 11)	Mean Temperature of Driest Quarter (Bio9)	Mean Temperature of Driest Quarter (Bio9)
<i>Cynometra forest</i>	2050	Annual Mean Temperature (Bio 1)	Precipitation of Coldest Quarter (Bio19)	Temperature Annual Range (Bio7)	Mean Temperature of Driest Quarter (Bio9)
	2070	Mean Temperature of Driest Quarter (Bio9)	Mean Temperature of Driest Quarter (Bio9)	Min Temperature of Coldest Month (Bio6)	Min Temperature of Coldest Month (Bio6)
<i>Mixed forest</i>	2050	Mean Temperature of Wettest Quarter (Bio8)	Mean Temperature of Wettest Quarter (Bio8)	Mean Temperature of Driest Quarter (Bio9)	Max Temperature of Warmest Month (Bio5)
	2070	Precipitation of Driest Month (Bio14)	Precipitation of Driest Month (Bio14)	Mean Temperature of Wettest Quarter (Bio8)	Mean Temperature of Wettest Quarter (Bio8)

The predictive model for the three vegetation types in Arabuko-Sokoke forest had various bioclimatic variables. These variables contributed differently to the model and they represent annual trends, seasonality and extremities of temperature and rainfall parameters. These climatic parameters are

supported by (Jarvis and Linder, 2000) study that noted the role climatic parameters associated with temperature and precipitation plays in determining plant growth and respiration processes. Increasing temperature is likely to affect nutrient availability in the soil through the stimulation of organic matter

decomposition and mineralization of soil nutrients and this observation could explain the projected increase in species area in Arabuko-Sokoke.

Because MaxEnt considers only niche-based presence data, it estimates the species fundamental niche (different from occupied niche) rather than realized niche (Kumar and Stohlgren, 2009, Yang *et al.*, 2013). To understand the fundamental niche a set of deterministic parameters are analyzed through statistical inference to estimate the bias and standard error in a statistic, when a random sample of observations is used to calculate (Phillips *et al.*, 2006).

The jack knife tests for the vegetation types confirms previous findings showing that variables associated with annual trends, seasonality and extremities of temperature and rainfall parameters contributed to the predictive model and determines forest biomass growth (Jarvis and Linder, 2000).

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Based on the results MaxEnt model can be used to predict geographical distribution of mixed and *brachystegia* vegetation based on general climate model scenarios of RCP4.5 and RCP8.5. The species distribution predictive model for Arabuko-Sokoke was strongly influenced by annual trends, seasonality and extremities of temperature and rainfall parameters.

4.2 Recommendations of the study

The role and contribution of the forests in the climate change mitigation and adaptation cannot be over emphasized. The impacts of climate on forest ecosystem is has been well documented, but the scale and magnitude is still an ongoing debate. Based on the study findings postulated species shift and niche reduction in Arabuko-Sokoke based on representative pathway concentration scenarios of RCP4.5 and RCP8.5. The study recommended the following;

- That the forest managers consider development of strategies to deal with possible shift species and fundamental

niche reduction for key species in Arabuko-Sokoke forest

- Communities are advised to diversify their sources of livelihoods and reduce their dependency on forest in the event the predicted shift of species range sets in
- Carbon accounting systems and GHG systems should take into consideration carbon accumulation and possible impacts of climate change on tree biomass in Arabuko-Sokoke

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