PREDICTING THE DISTRIBUTION OF THE INVASIVE SPECIES
HYPTIS SUAVEOLENS IN NIGERIA

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ABSTRACT

Hyptis suaveolens is an exotic plant that has become established in Nigeria because it is grows vigorously and produces allelochemicals that adversely affect the growth of adjacent plants. In this study, we predict the distribution of *Hyptis suaveolens* in Nigeria using a Maximum Entropy modelling approach. Pearson correlations were used to select five bioclimatic variables to which type of soil and altitude were added to give a total of seven environmental variables that were then included in the MaxEnt model. This model predicts that *Hyptis suaveolens* can colonize 25%, 45% and 25% of the total land area in FCT, Nasarawa and the River States in Nigeria. In addition, *Hyptis suaveolens* in Nigeria grows mainly in sandy clay and sandy loam soils. Bioclimatic conditions most suitable for this species include temperatures between 26–30 °C, 9–10 hour photoperiod, low altitudes of around 200–800 m and rainfall within the range of 200–800mm. The MaxEnt model indicates that *Hyptis suaveolens* is currently a threat to the survival of native species of plants in the North Central part of Nigeria. The MaxEnt model further reveals that because of its high adaptability and tolerance of changes in abiotic factors, *Hyptis suaveolens* is likely to invade a new environment, the humid forest zone in Nigeria. As this species can become very abundant, we recommend that its spread is monitored and controlled, particularly in areas of high suitability.

Keywords: climatic factors; *Hyptis suaveolens*; MaxEnt model; Nigeria; invasion

Introduction

Biological invasions are seen as threats to plant biodiversity, as they can alter the vegetation and change habitats (Mack and D'Antonio 1998; Mack et al. 2000) and thus reduce diversity (Meiners et al. 2001). In addition, invasion can reduce species richness through interspecific competition (D'Antonio et al. 1998; Christian and Wilson 1999; Parker et al. 1999; Meiners et al. 2001). Invasive species usually compete with native plants, which eventually affects species evenness in communities (Sharma et al. 2009). Invasive alien species (IAS) affect native plants by competing for space and nutrients (Borokini 2011). Global invasive species database documents 6 species of grass, 6 shrubs, 8 trees, 8 herbaceous plants and 2 sedges occurring in Nigeria whereas, Borokini (2011) identifies 25 IASs in Nigeria, but does not include *Hyptis sauvolens*. In total, 487 protected sites in the world are under threat and protected areas in 106 countries are seriously under siege from IASs (De Poorter et al. 2007).

Hyptis suaveolens (L.) is among the most damaging of the invasive species invading a wide range of ecosystems in tropical and sub-tropical regions in the world (Sarmiento 1984; Afolayan 1993; Padalia et al. 2014). *Hyptis suaveolens* is an annual herbaceous plant belonging to the family Lamiaceae. It thrives in high rainfall warm tropical and sub-tropical regions. Also, it can survive in semi-arid areas, where it propagates by means of seed. Optimal growth of *H. suaveolens* is recorded between 25 to 30 °C and it can germinate at temperatures between 10 to 40 °C (Felippe et al. 1983). In savannah, dominance of *H. suaveolens* is mainly associated with land from which humans have removed the vegetation by burning or over-grazing (Wulff 1987). It grows rapidly in cultivated fields and disturbed sites, especially where mechanized farming and intense cattle grazing are practised (Holmes 1969). This plant also grows along roadsides and watercourses. It has a strong tendency to grow abundantly in open woodlands and rangelands. It produces a dense growth and releases allelochemicals, which inhibit the germination of the seeds and growth of indigenous species.

Moreover, prolific seed production (Raizada 2006), easy dispersal (Parsons and Cuthburtson 2000) and phenotypic plasticity means this species can colonize many habitats (Sharma and Raghubanshi 2009). The release of unpleasant scent makes it unpalatable for livestock and partly accounts for its abundance over a broad ecological range. The proliferation of *Hyptis* is characterized by some morphological features that enable it to grow in poor quality soils, such as the small size of its seed, seed dimorphism, auto gamic and allogamic reproduction and vigorous growth from perennating rootstocks (Raizada 2006).

Climate is an important factor affecting plant distribution (Catford et al. 2009; González-Moreno et al. 2013). Global climate change has focused attention on the prediction of plant distribution and likely future trends
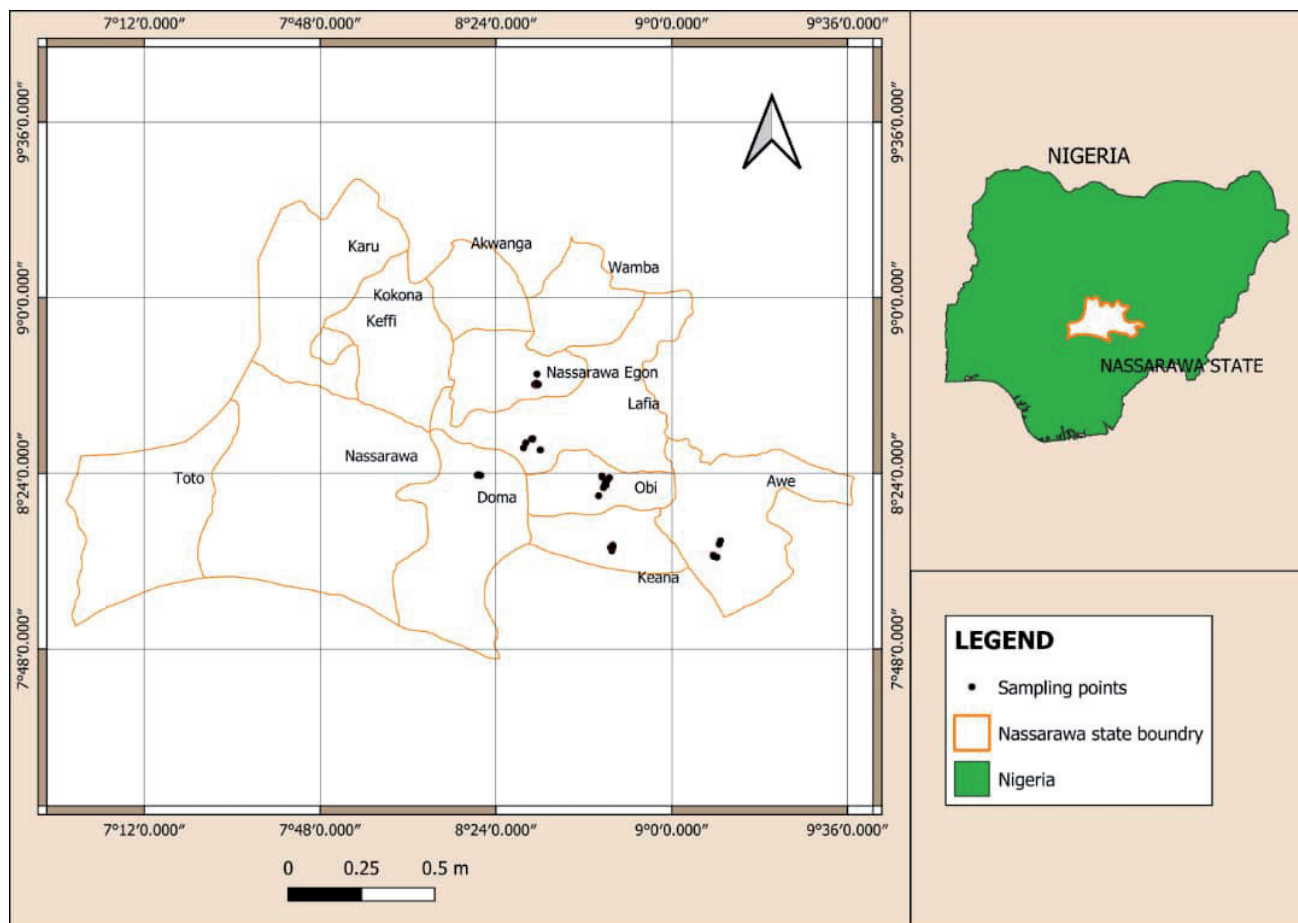
Fig. 1 The sites where *Hyptis suaveolens* occurred in Nasarawa State, Nigeria.

(González-Moreno et al. 2013). The MaxEnt model helps us understand the highly complex relationships between the occurrence of species and their environments (Busby 1991; Phillips et al. 2006). It compares their coordinated geographical data in terms of climate factors in order to predict their probable distributions (Guillera-Arroita et al. 2014; Shabani et al. 2018). Predicting the potential distribution of *H. suaveolens* will facilitate the development of the methods needed to curtail its adverse effect on native species. Currently, the potential distribution of *Hyptis suaveolens* in Nigeria is unknown. This study, therefore, aims to predict the potential distribution of *Hyptis suaveolens* in Nigeria using a Maximum Entropy modelling approach.

Material and Methods

Study area

This study was carried out in Nasarawa state, which is situated between latitude 8°25′40″N and longitude 8°39′19″E. The sampling was carried out in 6 local government areas (LGAs) including Awe, Keana, Obi, Eggon and Lafia. The spatial data for this plant at each site was collected using a quadrant of size 20 × 20 m. *Hyptis suaveolens* was sampled at 76 different locations for which

the latitude, longitude and altitude were determined using a GPS device (Fig. 1).

Environmental data

Environmental variables used in the model were downloaded from WorldClim (worldclim.org). The bioclimatic data were obtained from monthly temperature and rainfall values and consist of 19 variables, which are listed in Table 1. The spatial resolution of these variables is 2.5 arc minutes. Digital Altitude Model (DEM) data were downloaded from USGS Earth Explorer. The soil type is a categorical variable and was obtained from data.mendeley.com (Nkwunonwo et al. 2020). ArcGIS 10.2.1 software was used for all the conversions and analyses used for the MaxEnt modelling.

It is likely that the bioclimatic variables are highly correlated with one another, which can affect the performance of the model. Therefore, a multicollinearity test was conducted, according to Pradhan (2016), using ENM Tools and based on Pearson correlation coefficients (r). The VIFs (Variance Inflation Factor), which were obtained using the formula $1/(1 - r^2)$, were analysed using Excel 2015 software. Errors due to multicollinearity were screened out using the standardized values of r > 0.8, r^2 > 0.8 and VIF value > 10, but values of r > 0.8 and VIF > 10 were also considered following Pradhan (2016). The

Multicollinearity test resulted in five bioclimatic variables being selected (Table 2).

Table 1 Description of bioclimatic variable prior to the Multicollinearity test.

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

Table 2 Bioclimatic variables remaining after the Multicollinearity test.

Code	Description
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal variation in temperature (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (×100)
BIO8	Mean Temperature in Wettest Quarter
BIO19	Precipitation in Coldest Quarter

The Soil type and DEM were included in a raster and then converted to an ASCII file with the same extent and cell size using ArcGIS 10.2.1. The soil types were categorized based on their texture. The ArcGIS 10.2.1 was used to produce a map of the locations of the sites sampled, along with the density, soil type and kriging interpolation.

Modelling

MaxEnt (Maximum entropy) version 3.4.1 was used to determine the potential distribution of *H. suaveolens* in Nigeria. Of the various models, the predictions of the MaxEnt model are often the most precise, possibly because they are based on applications, such as domain, and bioclimatic and logistic regressions (Hijmans and Graham 2006; Phillips and Dudik 2008). MaxEnt evaluates the habitat suitability of a targeted species by analysing the maximum entropy of the environmental variables of species occurrence data. (Phillips et al. 2006). Even when there are data for only a few occurrences, this model still gives an accurate prediction. The MaxEnt generated continuous outputs with ten replicates using subsample replication and the averages of the replicates are presented. A maximum of 1000 iterations was allowed.

Model evaluation

The curves of the species responses to predictors predicted by the model were analysed to determine the patterns. Jackknife test was used to assess the contributions of individual variables to the MaxEnt predictions. In the Jackknife test, the training loss/gains for all the variables, without the specific variable, and with each variable in isolation, were used to evaluate the model. This was done for all the predictor environmental variables used in the model (Padalia et al. 2014) Receiver operating characteristic (ROC) area under curve (AUC) method was used to determine the performances of the MaxEnt model (Shabani et al. 2018). The AUC provides a single measurement of model performance, independently of any particular choice of threshold. The value of the AUC ranges from 0 to 1, indicating the model performance. This method is widely used for comparing the performances of species distribution models (Padalia et al. 2014).

Spatial distribution

The occurrence data for *H. suaveolens* was converted to Shp (Shapefile) and used to map the density of occurrence on-site and kriging interpolation generated for density.

Results

The soils at locations where *Hyptis suaveolens* was recoded in Nasarawa state, Nigeria, varied from sandy clay-to-clay loam (Fig. 2). Considering the density of occurrence of *H. suaveolens*, the results show that the density of this plant ranged from 9–11 plants/m² at the six areas studied (Fig. 3). However, the highest density occurred in Awe LGA and lowest in some parts of Lafia, Doma, Obi and Keana (Fig. 4). The AUC test ranged from 0.972–0.991 and Training AUC ranged from 0.985–0.992 (Fig. 5). The average AUC for the replicate runs is 0.982 and the standard deviation is 0.007, which indicate that MaxEnt prediction of the distribution of *Hyptis suaveolens* in Nigeria is accurate (Fig. 5). The Maxent model revealed that the omission rate of the training and test portions of the data is zero. This indicates that this model correctly predicts the presence *H. suaveolens* in the areas that are 100% suitable for its invasion. The average AUC of the ROC for the training and test data of the MaxEnt model is 0.988 and 0.982, respectively, whereas that of random prediction is 0.5. This reveals that this model accurately discriminates between the suitable and unsuitable habitats for *H. suaveolens*.
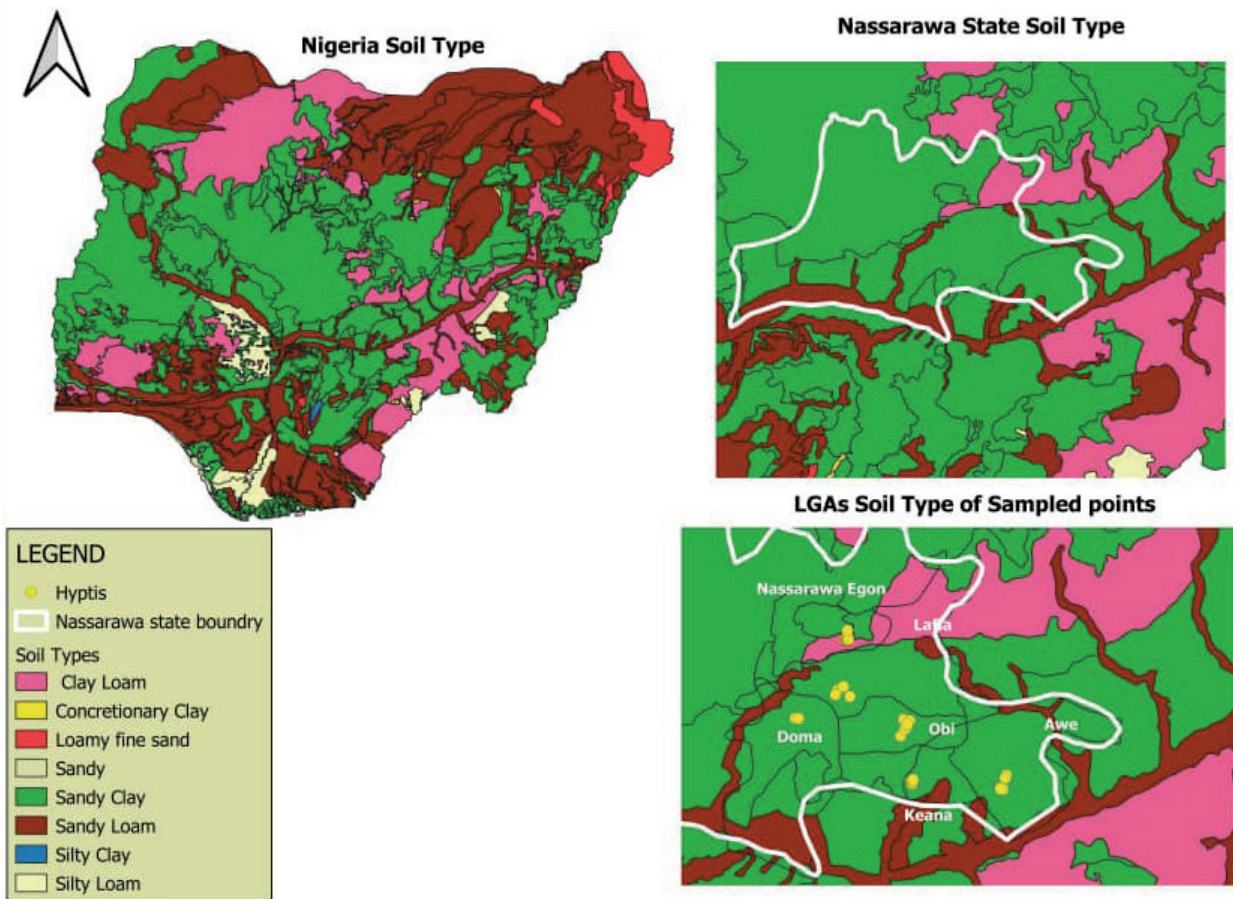
Fig. 2 The distribution of the different types of soil at localities where *H. suaveolens* occurred in the area studied.
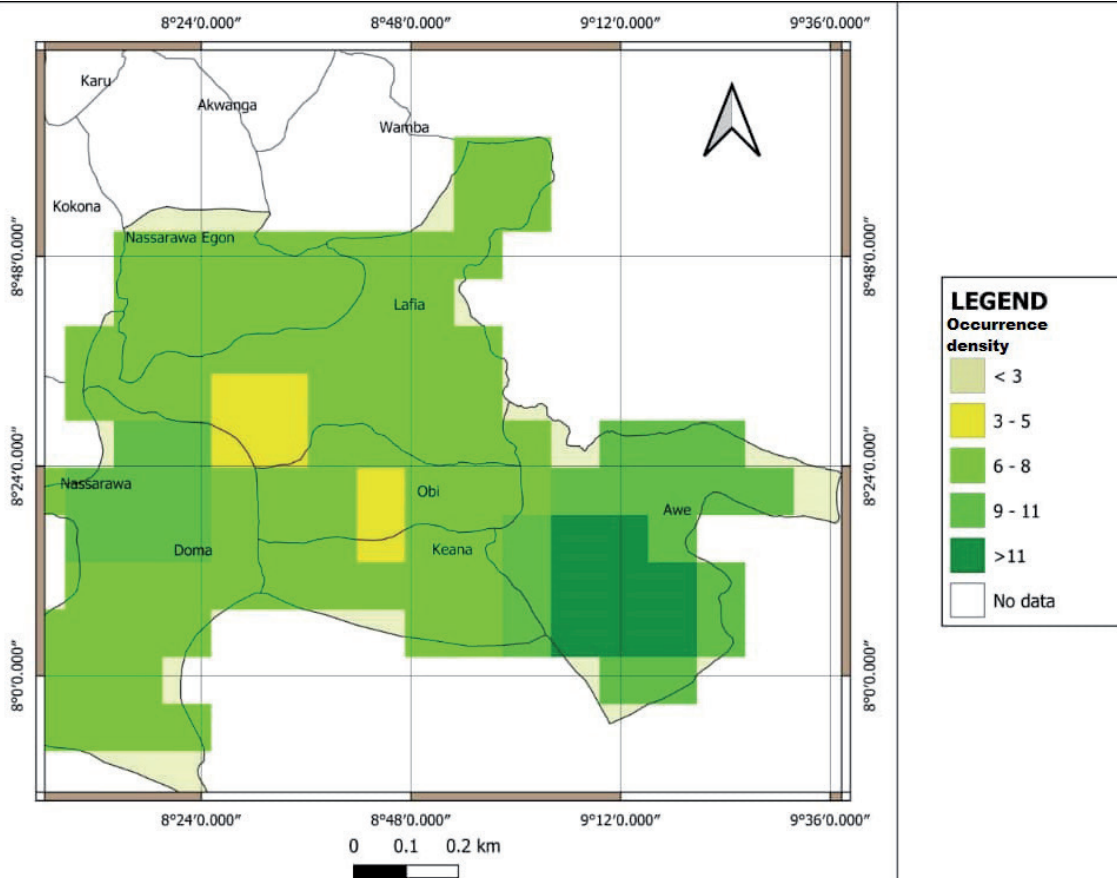

Fig. 3 The density of occurrence of *H. suaveolens* in particular areas in Nasarawa State, Nigeria.
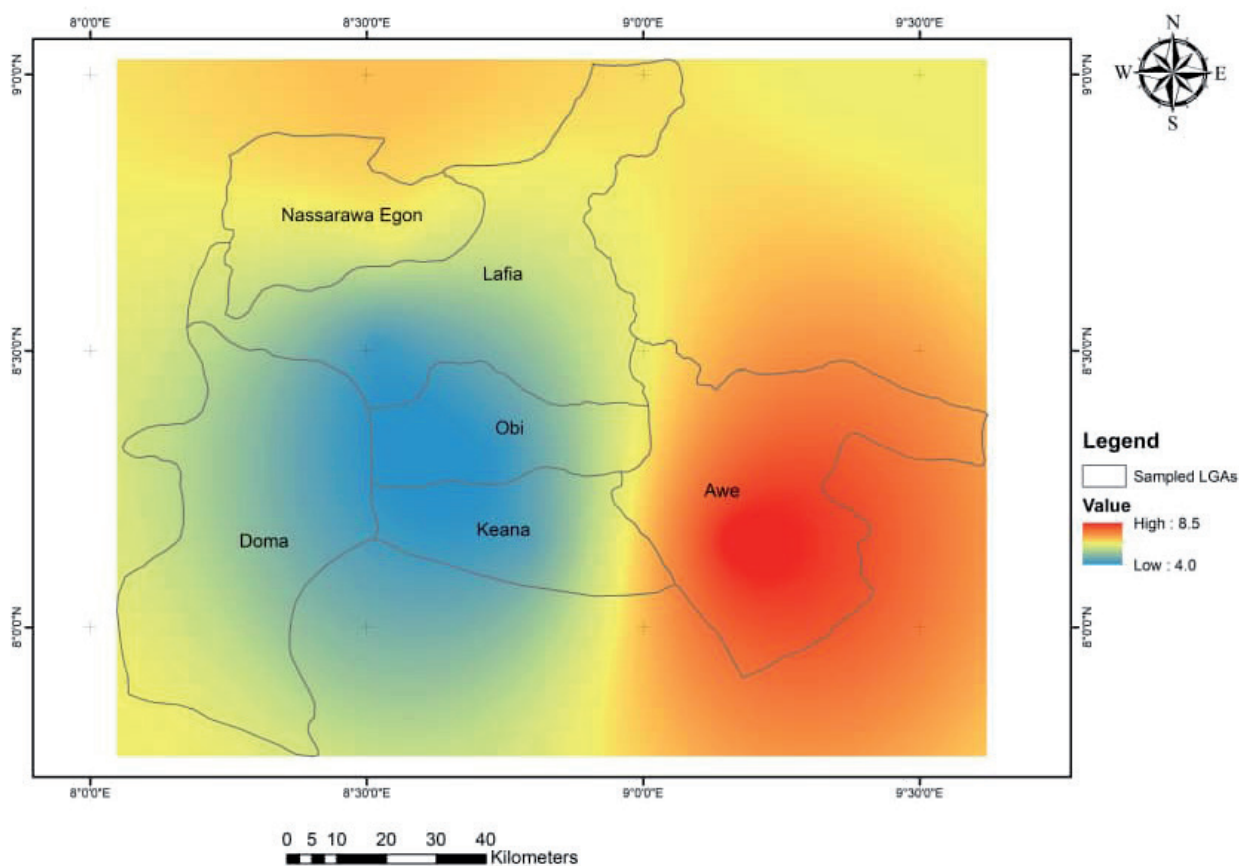
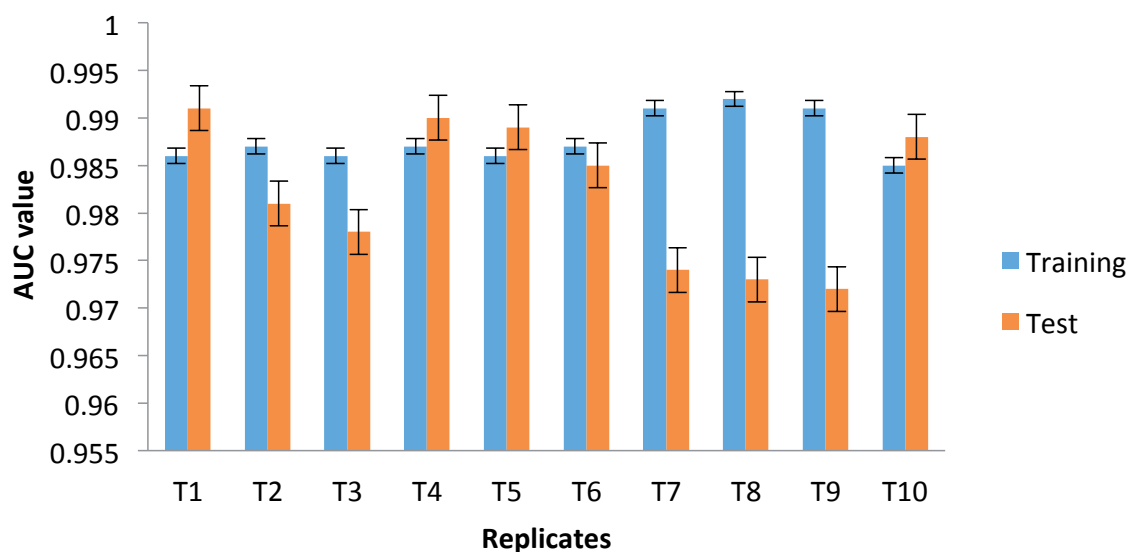**Fig. 4** Kringing Interpolation of the density of occurrence.

Fig. 5 Evaluation of the Test and training AUC values of the ten-cross-model validations.

The model can be used to predict with a probability of between 0.62–1.00 those areas in Nigeria that are suitable for *H. suaveolens*. The nine areas predicted to be most suitable for *H. suaveolens* in Nigeria include Abuja (FCT), Nasarawa, Plateau, Taraba, Adamawa, Cross River, Bayelsa Rivers and Abia (Fig. 6). Of the nine states, three are in the North Central, 2 in the North East, 3 in the South-South and 1 in the southeast zone (Table 3). All the other states in Nigeria are predicted to be less suitable

for this plant. It is predicted that the highest percentage of the land (47.5%) likely to be invaded by *H. suaveolens* in Nigeria is in Nasarawa State, followed by Rivers and Abuja, with 25% (Table 3). The least affected State is Adamawa for which the prediction is 1.49%. The Jackknife analysis used to identify the contributions of each of the predictor abiotic variables revealed that isothermality on its own was not important (Fig. 7). Soil type was the only variable that was important on its own. The effects of all

Table 3 Areas of land predicted to be affected by *H. suaveolens* in Nigeria.

| S/N	Name of State	Geopolitical Zone	Total Area (km²)	Area predicted to be affected (km²)	Percentage of the area affected (%)
1	Abia	South East	4723.46	429.41	9.09
2	Abuja (FCT)	North Central	7353.15	1838.29	25
3	Adamawa	North East	34323.63	512.29	1.49
4	Bayelsa	South-South	10173.35	678.22	6.67
5	Cross River	South-South	21153.35	515.94	2.44
6	Nasarawa	North Central	26313.58	12500	47.5
7	Plateau	North Central	27562.53	1968.75	7.14
8	Rivers	South-South	9100.54	2275.14	25
9	Taraba	North East	60115.8	1134.3	1.89
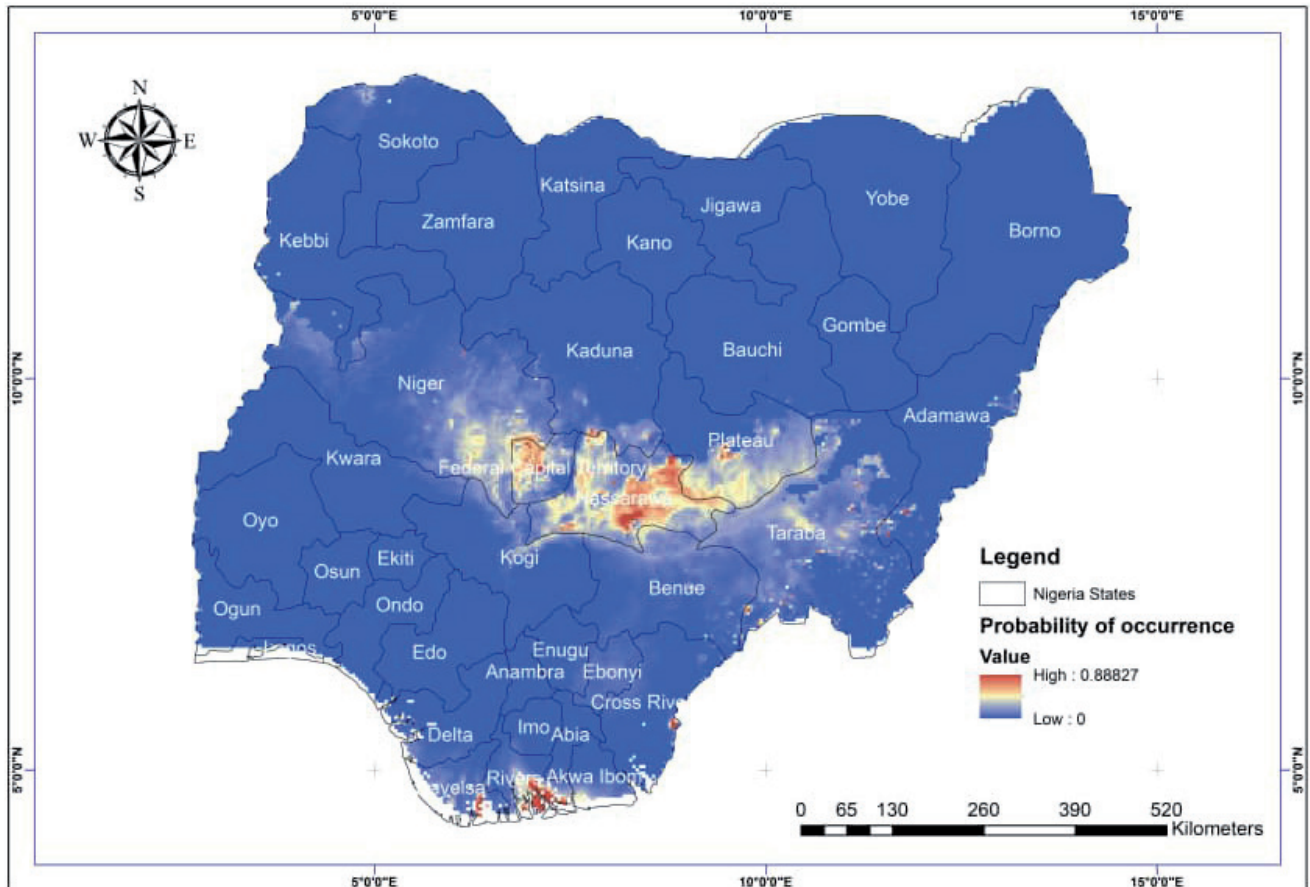
Fig. 6 Map showing the predicted probability of occurrence of *H. suaveolens* in Nigeria.
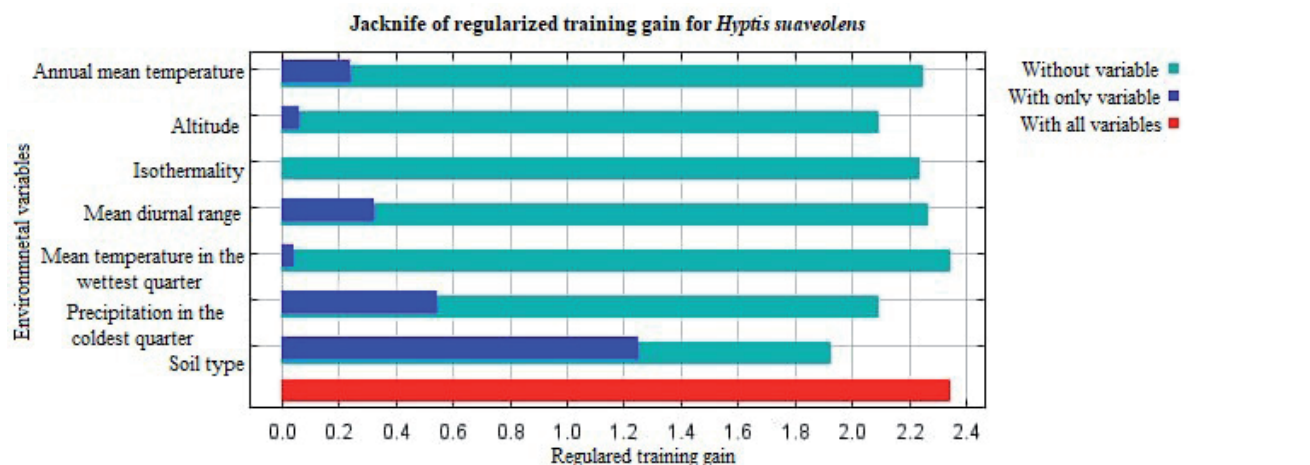

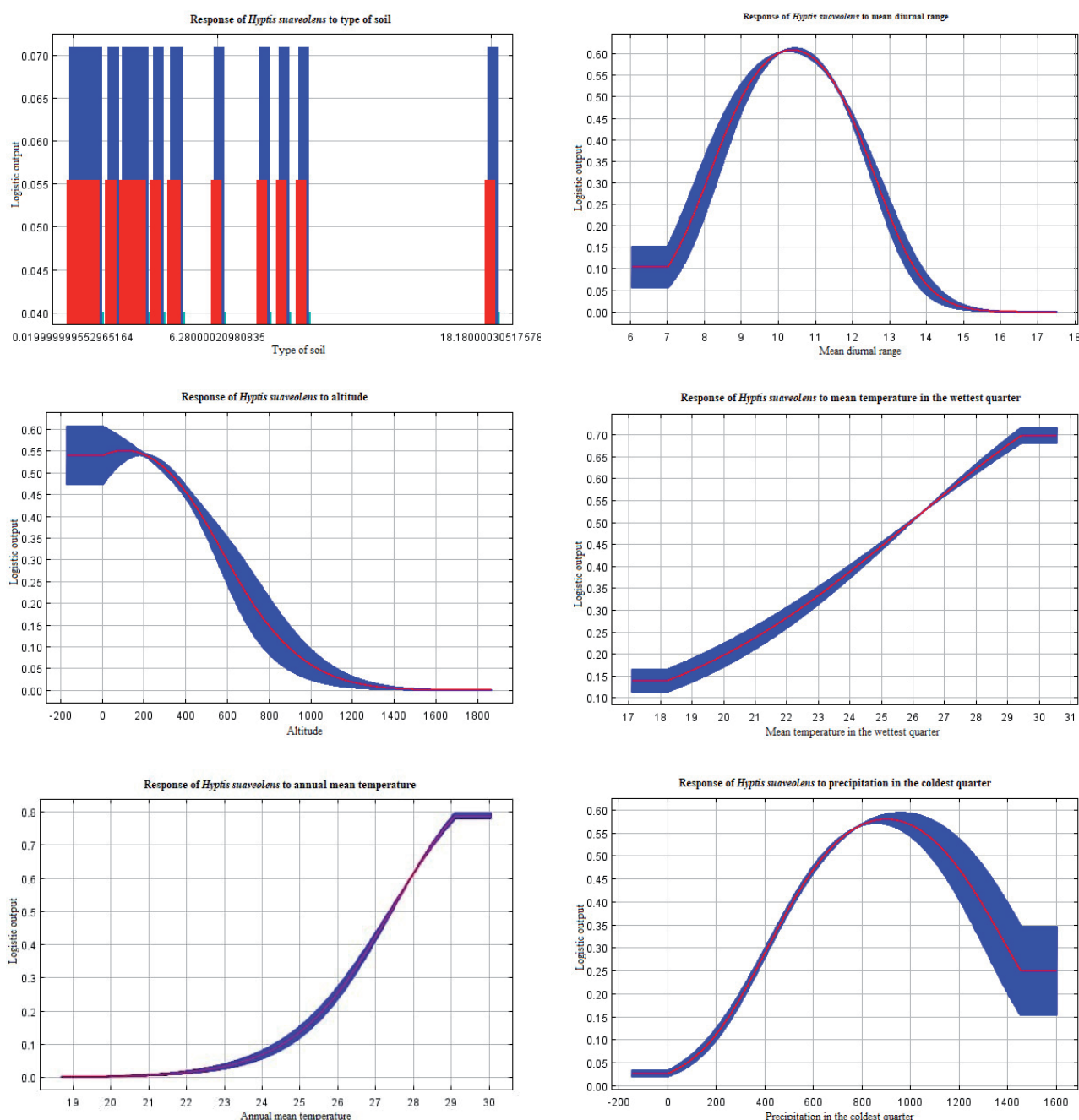**Fig. 7** Jackknife plots of the training data.

Fig. 8 The responses of *H. suaveolens* to (A) type of soil, (B) mean diurnal variation in temperature, (C) altitude, (D) mean temperature in the wettest quarter, (E) annual mean temperature and (F) precipitation in the coldest quarter. Red curves = mean response and blue margins = ±1 SD based on 10 replicates.

the variables based on their respective contributions are depicted in Figure 7. These are regarded as the most important predictors of the areas likely to be invaded by *H. suaveolens* in Nigeria. Their individual percentage contributions to the prediction are: soil type (52.08%), mean diurnal variation in temperature (12.5%), precipitation in the coldest quarter (22.08%), annual mean temperature (9.5%), mean temperature in the wettest quarter (2.08%) and altitude (3.7%). Probability of *H. suaveolens* occurring at high altitudes (above 1000 m) was < 0.05 and for those occurring between 200–800 m ranged between 0.15–0.5. The probability of its occurrence (> 0.5) increased with increase in the mean temperature in the

wettest quarter (26 °C to 30 °C). Favourable precipitation in the coldest quarter ranged from 200–800 m. The probability of an area being invaded by *H. suaveolens* (> 0.5) increases when the mean diurnal variation in temperature is > 0.5, photoperiod less than 10 hours and the isothermal is 50–60 J K⁻¹ (Fig. 8).

Discussion

Hyptis suaveolens in areas already invaded is abundant and spreading rapidly, resulting in the homogeneity of floras, reduced biodiversity and a reduction in the ecolog-

ical integrity of the native habitats and ecosystems functioning (Hulme et al. 2003; Borokini and Babalola 2012). It has caused a 46–52% decrease in species evenness in the periurban ecosystems in Chandigarh, north-western India (Sharma et al. 2017). There are invasive potential hotspots of *Hyptis suaveolens* in Abia, Adamawa, Bayelsa, Cross River, Nasarawa, Plateau, Rivers, Taraba and Rivers States, especially between latitude 8°52′N and 12°07′E in areas with derived savannah, which have suitable climatic conditions. Derived savannah is disturbed forest, which was cleared mechanically, or by burning or manual hand-weeding for agricultural purposes, which – when abandoned – are colonized by grasses. Recurrent fires and overgrazing are also frequent in this ecological zone. *Hyptis suaveolens* is described as an invader of grassland. This weed grows vigorously in agricultural fields, rangelands, pasture, floodplains, open woodlands, roadsides and disturbed areas (Raizada 2006; Padalia et al. 2014). It is predicted that the Federal Capital Territory (FCT) and Rivers State has suitable eco-climatic conditions and is very likely to be invaded by this plant, which could seriously reduce the biodiversity in this humid forest zone. This is because *H. suaveolens* thrives in a wide range of climatic conditions. The ecological amplitude and seed dimorphism of this species enables it to germinate over a wide range of temperatures, which results in year-round seed germination (Raizada 2006). The seeds of *H. suaveolens* are capable of germinating at temperatures between 10 °C and 40 °C, but 25–30 °C seems to be the optimum for growth (Felippe et al. 1983).

Importantly, this plant prefers sandy clay and sandy loam soils, which further broadens the range conditions in which it can survive. This may enable it to thrive in new environments such as Benue, Kogi, Niger, Kaduna and Bauchi States, in the future. Similarly, *H. suaveolens* thrives in sandy soil with a high pH, low fertility and is well-drained (Aboh et al. 2017), which with climate change could result in it invading new habitats (Padalia et al. 2015).

The results also indicate that the mean temperature in the wettest quarter, annual mean temperature, altitude, diurnal variation in temperature and precipitation in the coldest quarter were the most important bioclimatic factors determining the survival and growth of *H. suaveolens* in Nigeria. Low temperature and low moisture environments limit its invasive potential worldwide (Padalia et al. 2014). It is well known that other climatic factors, such as moisture balance and extreme temperatures, determine plant distribution (Stephenson 1990; Widrlechner et al. 2012; Zhang et al. 2020). Several studies report the effect of moisture and extreme temperatures on the physiological characteristics of plants, such as growth, yield, flowering and tolerance (Tandazo-Yung et al. 2017; Song et al. 2018).

Type of soil, diurnal variation in temperature, altitude, precipitation and temperature are significant factors determining the distribution of the targeted plant. In addition, areas with lower mean diurnal variation in temperature at low altitudes are more prone to being invaded. High abundances of *H. suaveolens* in Nigeria occur mainly at altitudes between 200–800 m, where the temperature is between 26 °C and 30 °C, rainfall between 200–800 mm with a photoperiod of 9–10 hours. Probability of occurrence is very low at altitudes above 1500 m, where conditions are too cold for this species (Padalia et al. 2014). Its occurs at an altitude ~1560 m in its native range in Venezuela, (GBIF 2013) and has invaded the central highlands at an altitude ~850 m in India (Padalia et al. 2014). It prefers wet and warmer environments, as it is an annual herbaceous plant originating from the tropics (Padalia et al. 2015). It is a short-day plant with optimum growth at temperatures ranging between 25 and 30 °C (Raizada 2006; Barbosa et al. 2013).

In this study, the MaxEnt model was used to predict the distribution of *H. suaveolens* in Nigeria. This revealed that abiotic factors such as type of soil, mean temperature in the warmest quarter, precipitation in the coldest quarter, altitude and diurnal variation in temperature are the most important factors determining its occurrence and distribution in Nigeria. Among these factors, type of soil was the most important. The model predicted a high occurrence of *H. suaveolens* in derived savannah in Nigeria (FCT, Nasarawa, and Plateau States) and because of its broad ecological tolerance a future occurrence in humid forest areas (Rivers and Cross Rivers States) in Nigeria, which would be a major threat to the native vegetation in humid forest. This invasion seriously threatens the survival of native plants in the most suitable areas, therefore, there is an urgent need to stop the spread and control the abundance of *H. suaveolens* in Nigeria.

Acknowledgements

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