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# Potential Impact of Climate Change on Six Economically Important Horticultural Crops in West Africa

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## **Author's contribution**

*The sole author designed, analyzed, interpreted and prepared the manuscript.*

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## **ABSTRACT**

*Colocasia esculenta* (taro), *Ipomoea batatas* (sweet potato), *Abelmoschus esculentus* (okra), *Ananas comosus* (pineapple), *Musa paradisiaca* (plantain), and *Anacardium occidentale* (cashew) are economically important horticultural crops in West Africa, which are widely grown across the region under rain fed conditions. They are very important set of crops that provides income for the individuals involved with it and thus contributing to economy of West African nation's. For Predicting the potential future habitat suitability of these crops under different climate scenarios holds significance for their continuous cultivation and effective management. The Maxent model was used in this study to predict habitat suitability of these crops under current and future climatic conditions based on two representative concentration pathways (RCP4.5 and RCP8.5) for the years 2050s and 2070s. The data used were the occurrence records from Global Biodiversity Information Facility (GBIF) and WorldClim's bioclimatic environmental predictor variables. The findings of this experiment showed that the habitat suitability of some crop species will decrease and in some it will increase. Suitable habitat was predicted to decrease within the semi-arid and

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arid areas of the region, especially on those countries in northern part which includes Niger, Mali and Burkina Faso, as early as by 2070s. For species like okra, sweet potato and taro, there will be further decline as predicted under the higher emission scenario of RCP 8.5. The suitable habitat for cashew remained stable for future in all the models and scenarios used. This work provides the first theoretical guidance for possible future cultivation of these horticultural crops in the West Africa.

**Keywords:** *Habitat suitability; maxent; modelling; projections.*

## 1. INTRODUCTION

Horticulture in West Africa is very vulnerable to the impacts of climate change and short-term weather extremes, for several reasons [1]. This industry has high dependence on rain-fed conditions, with inadequate infrastructure facilities (e.g. irrigation) [1] to counter climate variability and drought. In addition, rapid human population growth has placed mounting pressure on water resources in the region [2]. This has resulted in strong variability of the major rivers and lakes, leading to an overall increase in water deficit [3]. These conditions have already had substantial impacts on horticulture. For example, between 1980s to 2000s, declines of up to 14% in fruit yield occurred in Benin and Burkina Faso due to changes in the environment [4].

West Africa has experienced warming of between 0.3 and 1.5°C in 2000s compared to the 1970s [5]. As the century progresses, projections of warming range from 1.5–6.5 °C, depending upon greenhouse gas emissions, with the Sahel likely to experience the greatest warming [6]. However, precipitation changes have a wide range of uncertainty, varying from -30 to 30% by 2100s compared to the 1980s baseline, with the Sahel expected to be 5-40% drier [7]. Further, the West African region is likely to experience fewer rainy seasons, and more arid and semi-arid conditions, although some areas may also have more intense precipitation [8]. These conditions will consequently result in significant stress to not only agricultural activities, but also to general ecosystem services and management and planning [8].

In this study, HSM MaxEnt v 3.3.3 k [9] was used to assess the distribution of current and future habitat suitability for six economically important horticultural crops in West Africa (Taro, Sweet Potato, Okra, Pineapple, Plantain and Cashew). These crops are widely grown across West Africa under rain fed conditions, with more than two million tonnes of each grown annually [9]. A machine learning algorithm, MaxEnt has been

widely used to model habitat suitability as it does not require absence data, and accommodates both continuous and categorical data [10]. Knowledge of potential changes in suitable habitats could help inform policy makers and management on measures and preparations that may ameliorate the risk posed by climate change.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

West Africa, with an area of about seven million square kilometres, represents approximately one fifth of Africa [10]. Located between 5°–35°N and 15E°–15W, it is bounded in the north by the Sahara Desert and in the south and west by the Atlantic Ocean. This area is characterized as having an 'intertropical front' climate, which depends on interactions between the humid features of the Atlantic Ocean and the dry and hot interior of the Sahara Desert [11]. These interactions drive both temperature and precipitation patterns. Significant variations in the northward displacement and intensity of the seasonal monsoon has led to the formation of distinct ecosystems and bioclimatic zones [12] resulting in various habitats, from rainforest to desert. Generally, the climate is unimodal in the north with annual rainfall <100 mm, and bimodal in the south and western coast with marked annual rainfall of >2000 mm [13-16]. West Africa's latitude also influences the range and maximum of temperature: in the humid south temperature varies little, whereas in the arid north temperatures can range from 0°C to more than 45°C. These climatic characteristics divide the region from north to south into five bioclimatic zones known as the Saharan, Sahelian, Sudanian, Guinean, and Guineo-Congolian Regions.

### 2.2 Species Occurrence Data

This study focuses on six important horticultural crops in West Africa. They also reflect a diversity

of environmental preferences. Occurrence records for each species were downloaded from the Global Biodiversity Information Facility (GBIF, <http://data.gbif.org>) accessed on June 2020), using the ‘gbif.keep’ function of the ‘rgbif’ package [17] in R version 3.6.1 [18]. Data were then cleaned by applying the following filters: (a) must contain latitude and longitude (i.e. coordinate cleaning); (b) not a fossil or literature specimen; and (c) recorded since 1 January 1951. This resulted in a total of 63,460 unique occurrence records.

### 2.3 Environmental Data

For baseline conditions, bioclimatic variables from the WorldClim database (v 1.4), at a spatial resolution of 2.5 arc-minutes (<http://www.worldclim.org>) [19] were downloaded. These data were developed from meteorological records that primarily spanned the period 1960–1990. WorldClim consists of 11 temperature-based and eight precipitation-based variables, that represent annual trends, seasonality, and monthly extreme conditions. Using the R package ‘gdalutilities’ [18] data were converted to Mollwoide Equal Area projection system (epsg: 54009) at a spatial resolution of 5 x 5 km, via bilinear interpolation.

GCM compare R with 30 climate models, for the year 2070 and RCP 8.5, for the 15 countries comprising continental West Africa (Fig. 1) was ran. From these, four GCMs which span a range of plausible futures and that are available via the Centres and Research Program on Climate Change, Agriculture and Food Security (CGIAR CCAFS) Climate data portal ([http://ccafsclimate.org/data\\_spatial\\_downscaling/](http://ccafsclimate.org/data_spatial_downscaling/) accessed 14/01/2020) were selected. These data were derived from anomalies of the original GCM data, which had been statistically downscaled using a thin plate spline spatial interpolation. Anomalies were then applied to the WorldClim v1.4 baseline. Furthermore, the Fajardo et al. [20] General Circulation Models (GCMs) compare R online applications, showed that the four climate models used had variation in the magnitude and direction of the predictions of climate change from the 30 GCMs (Fig. 2).

All habitat suitability models and analyses of results were undertaken in R, using custom R code based on the following packages: rmaxent [21] raster and dismo [22]. The flow chart of the methodology used for study is summarized in Fig. 3.

## 3. RESULTS

For the six horticultural crops species modelled, the average AUC was 0.8 (SD = 0.008) (Table 1). This value indicated a fair to good performance for the classifier [23]. Different sets of variables were selected for each crop (Table 2). Under current conditions, the habitat suitability obtained in this modelling is compatible with general knowledge of their distribution. Most of the areas of suitable habitat were reported within the Savannah areas of Sudanian and Sudano-Guinean bioclimatic (eco) zones of West Africa

### 3.1 What Proportion of the Areas May Be Suitable in the Future? (Figs. 5–8)

**Cashew:** Of the six crops in West Africa, cashew has the second greatest distribution of climatically suitable habitat, extending from the coast through to Burkina Faso and the southern regions of Mali and the south-west corner of Niger. As the century progresses there is substantial consensus across the four climate scenarios that most regions currently suitable will continue to remain so. Further, the size of suitable habitat is projected to increase between 27–42%, by 2070s (RCP 8.5), depending upon the future scenario.

#### 3.1.1 Sweet Potato

Future habitat suitability for Sweet Potato in West Africa is predicted to be mostly across the southern part of the region. The areas that are projected to remain suitable extend from central Nigeria to coastlines of Senegal. Some scenarios showed that the whole Ghana may be suitable as the century progresses. There may be up to 5% increase in habitat suitability at RCP 4.5 by 2050s. However, the result of the model also showed 14% decrease (RCP 8.5 at 2070s) in the habitat suitability of this crop.

#### 3.1.2 Okra

The model showed that of the six horticultural crops studied in the work, Okra has largest projected suitable habitat. The model identified that it is only the coastal areas and arid parts of West Africa, which includes areas in Northern-Niger, Mali and Northeast of Mauritania that will not be suitable for this crop. The highest decrease in the habitat suitability for okra was also observed at RCP 8.5 by 2070s, ranging

from 4-15%. Therefore, the areas within the middle parts of West Africa region are going to remain suitable for the cultivation of Okra under all scenarios.

### 3.1.3 Pineapple

The future projections for habitat suitability of this crop suggest that it is primarily in south-western West Africa that areas currently suitable may remain so under all scenarios. There is considerable uncertainty across the other countries. The decrease in habitat suitability ranges from 12 to 61% under this high emission scenario, while in the medium emission scenario of the same year (4.5 RCP, 2070s), it may be from 12 to 34%. The result from the model also suggested that by 2070s under RCP 8.5, areas in south-eastern and central Nigeria then expanding westwards to include all the countries that are in the southern part of the region will be the only suitable areas for pineapple production in West Africa.

### 3.1.4 Plantain

As the century progresses, habitat suitability for plantain is predicted to be similar to that of sweet potato. The areas that may remain suitable include all the coastal lines from southern Senegal through central Guinea to central Nigeria. Under the RCP 8.5 by 2070s, decreases in the suitable habitat of this crop will range from 7-14%, and are projected to occur in the northern range margin. The commercial production of plantain under natural conditions may be restricted to areas at the southern parts of the region as shown by model under most scenarios.

### 3.1.5 Taro

There are few areas projected to remain suitable under all scenarios for this crop. However, this may involve areas in southern and central Nigeria, then extending through the coastal line westwards to include areas in south-west Ghana and then northbound to the whole of Guinea. As the century progresses, it is predicted that habitat suitability will decline substantially under RCP 8.5 by 2070s, where suitability is estimated to decrease by up to 70%.

## 4. DISCUSSION

This study modelled possible future habitat suitability for six economically important horticultural species in West Africa, using the

Maxent habitat suitability model. The projections showed that more than 20% of the current suitable habitat may change under climate scenarios for West Africa. As such, my models indicate that climate change may threaten habitat suitability of rain-fed West African horticulture production. This research reiterates the need for proper investment in climate change mitigation facilities like provision of irrigation, protected environmental crop production systems and other possible sustainable management plans.

Wang et al. [24] also found that projected climate change may cause loss of suitable habitat for plant species. A decrease in habitat suitability for horticultural crops in West Africa could lead to greater food insecurity and loss of economic opportunities [25]. Therefore, this work is very important. The results suggest that, of the six crops, the short-lived crops like okra, sweet potato and taro may be vulnerable to climate changes by 2050s. Thus, there is a need for more appropriate management planning immediately, for example, policy makers (especially the individual respective national governments) should make provision for major investment in irrigation facilities and other related infrastructures. Models also indicate that by 2070s even greater reductions in habitat suitability may occur in West Africa for these horticultural crops. Although cashew is the only perennial horticultural tree species used in this experiment, there is possibility that similar plants may be less affected by projected climate change. However, there is still a need to pay attention to their response, considering that other variables may also influence the suitability of an area for a given crop (e.g. soil) were not included in the current study.

### 4.1 Implications for Current Rain-fed Horticultural Crops Production

From this work, some of the horticultural crops modelled may face reductions in the extent of suitable habitat. These species should be considered more vulnerable to climate change in West Africa, under these climate scenarios. Furthermore, there is need to plan effectively for species with the same or similar climate and environmental requirements. Plant species with similar climatic requirements to cashew, a perennial horticultural tree fruit crop, projected to have expansions in suitable habitat, and may be more suitable for this region in the future. The modelling results indicate that West African hotspots can be described as those areas within

the semi-arid and arid areas of the region especially those countries in the northern part of the region, which includes places in Niger, Mali and Burkina Faso. The model showed that the impact of climate change on habitat suitability of horticultural crops is generally projected to be more adverse within the Sahel (desert) zones of WA, compared to the Guinea (coastal) areas.

#### 4.2 Limitation of this Model

Habitat suitability models (HSMs) are used to evaluate the potential distribution of suitable habitat for a species in a given landscape [26]. Limitations in HSMs may occur for reasons which include: (1) limitations in occurrence data, (2) selection of background points, (3) selection of threshold, and (4) adaptation to the environment.

Ideally, records from the species' entire distribution should be used to fit models, thereby ensuring that the model captures the breadth of the species' realised niche [27]. Typically, records from GBIF or similar online databases are used, however it is important to note that these may still be inadequate to capture the range of conditions the species can tolerate. This is because a species' realised niche may not span its fundamental niche, due to biotic factors, but also because not all places with populations may have been sampled. Alternative sources of

occurrence records include literature, government or agricultural society databases, but sometimes these are difficult to obtain. In addition, many of these records may not be at the appropriate geographic resolution [27].

It is important to state that this modelling analysis did not consider the potential for these horticultural crops to adapt to climate change. Neither did it account for the ability to modify the environment such as via irrigation, which may increase the suitability of regions that receive little natural rain. Furthermore, models of this type only consider exposure to climate change, however species responses may also include adaptation potential [28] or modification of the environment [29].

**Table 1. Area under the receiver operating characteristic curve (AUC) for each of the six horticultural crops modelled**

Crop	AUC (Standard deviation)
Pineapple	0.8 (0.005)
Cashew	0.8 (0.009)
Plantain	0.9 (0.015)
Sweet Potato	0.7 (0.010)
Okra	0.9 (0.008)
Taro	0.7 (0.005)
Model average	0.8 (0.008)

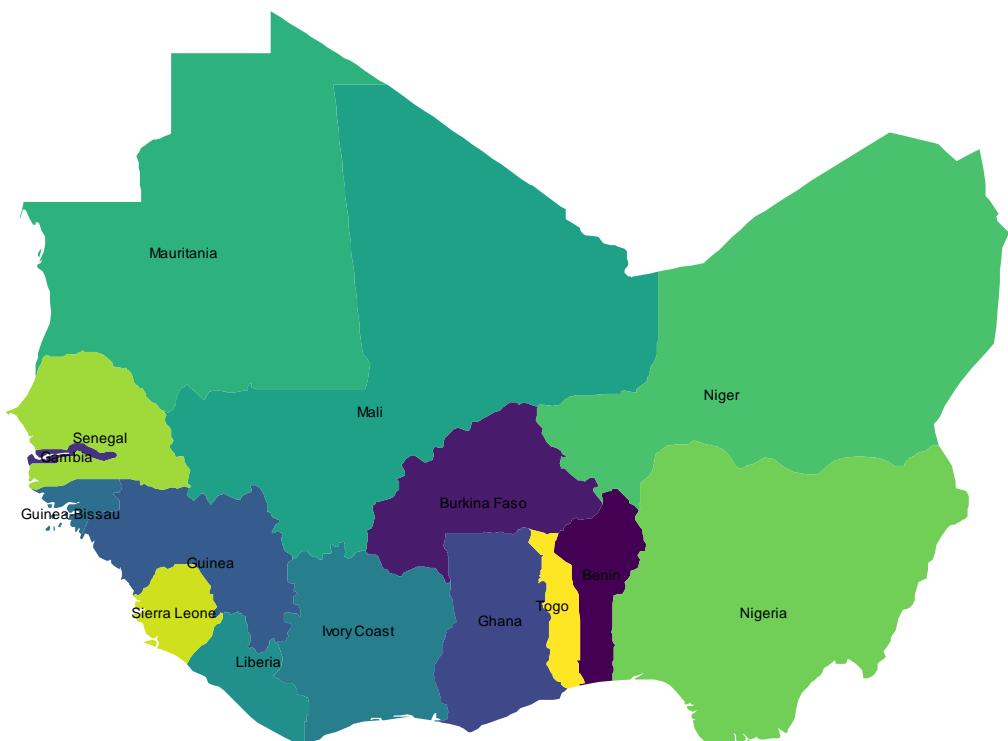
**Table 2. The number of occurrences for each plant species modelled and the Bioclimatic variables with their contributions to the model**

Horticultural Crops	Bioclimatic variables	Percent contribution	Permutation importance	Occurrence records samples	Background points
Okra	Bio 1	33.4	10	2081	51143
	Bio 5	26.5	34.9		
	Bio 15	17.9	3.2		
	Bio 4	6.5	5.3		
	Bio 6	5	26.8		
	Bio 14	5	13.9		
	Bio 13	4.2	1.6		
	Bio 12	1.4	4.3		
Taro	Bio 6	28.8	37.7	2963	51748
	Bio 4	19.7	21.5		
	Bio 15	16	0.7		
	Bio 14	15	1.7		
	Bio 1	10.5	34.9		
	Bio 5	7	2.5		
	Bio 13	1.5	0		
	Bio 12	1.5	1		

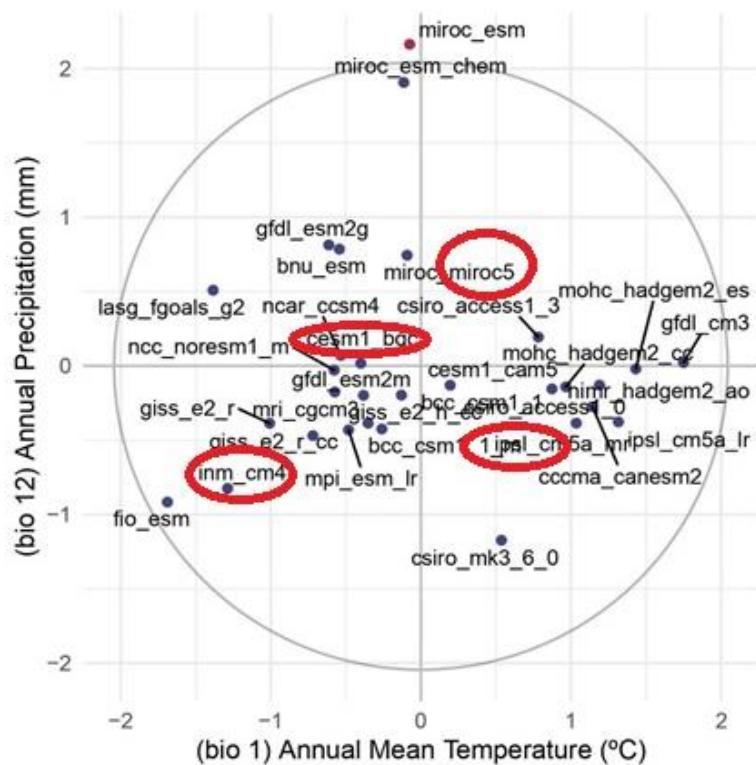
Pineapple	Bio 4	38.9	32.4	1206	50734
	Bio 1	18.7	9		
	Bio 6	16.7	12.9		
	Bio 5	7.5	18.6		
	Bio 15	6.9	7.6		
	Bio 14	5.6	14.6		
	Bio 12	5.4	4.9		
	Bio 13	0.3	0		
Cashew	Bio 1	34.9	9.3	3165	51473
	Bio 6	33.3	35.4		
	Bio 5	12.3	23		
	Bio 4	8.8	8.9		
	Bio 13	4.4	7.2		
	Bio 15	3.7	8.4		
	Bio 12	1.8	5.3		
	Bio 14	0.9	2.5		
Plantain	Bio 4	41.1	4.7	998	50813
	Bio 14	16.1	15.7		
	Bio 6	14.3	43.6		
	Bio 12	11.2	3.3		
	Bio 15	8	5.7		
	Bio 1	4.9	24.2		
	Bio 5	3.7	2.4		
	Bio 13	0.8	0.4		
Sweet potato	Bio 4	68	40.2	5357	52616
	Bio 15	11.5	2.9		
	Bio 1	5.2	19.7		
	Bio 12	5.1	11.1		
	Bio 6	5	10.6		
	Bio 14	3.5	8.8		
	Bio 5	1.2	2.4		
	Bio 13	0.4	4.3		

**The bioclimatic variables are coded as follows:**

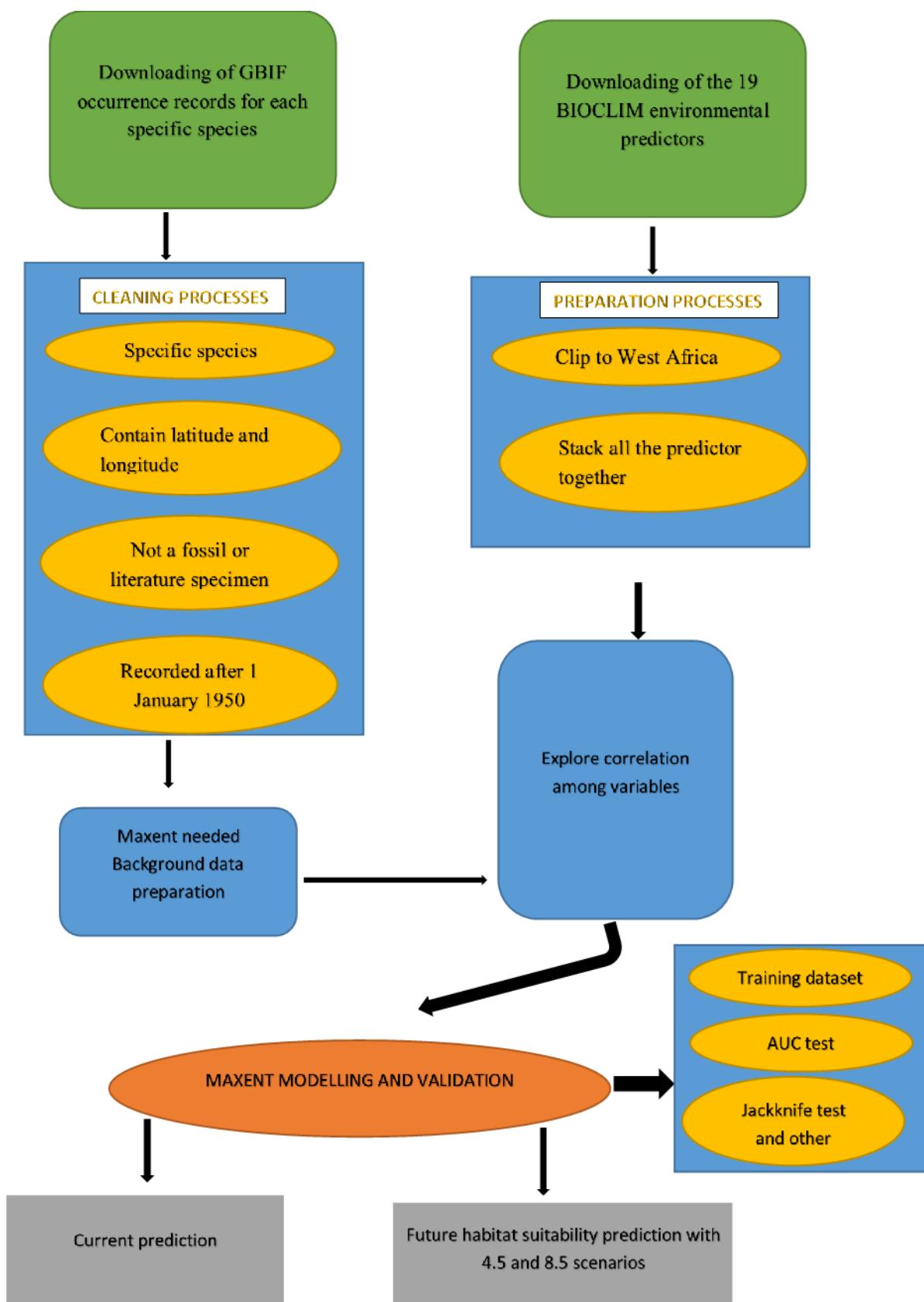
- BIO 1 = Annual Mean Temperature
- BIO 2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))
- BIO 3 = Isothermality (BIO2/BIO7) ( $\times 100$ )
- BIO 4 = Temperature Seasonality (standard deviation  $\times 100$ )
- BIO 5 = Max Temperature of Warmest Month
- BIO 6 = Min Temperature of Coldest Month
- BIO 7 = Temperature Annual Range (BIO5-BIO6)
- BIO 8 = Mean Temperature of Wettest Quarter
- BIO 9 = Mean Temperature of Driest Quarter
- BIO 10 = Mean Temperature of Warmest Quarter
- BIO 11 = Mean Temperature of Coldest Quarter
- BIO 12 = Annual Precipitation
- BIO 13 = Precipitation of Wettest Month
- BIO 14 = Precipitation of Driest Month
- BIO 15 = Precipitation Seasonality (Coefficient of Variation)
- BIO 16 = Precipitation of Wettest Quarter
- BIO 17 = Precipitation of Driest Quarter
- BIO 18 = Precipitation of Warmest Quarter
- BIO 19 = Precipitation of Coldest Quarter



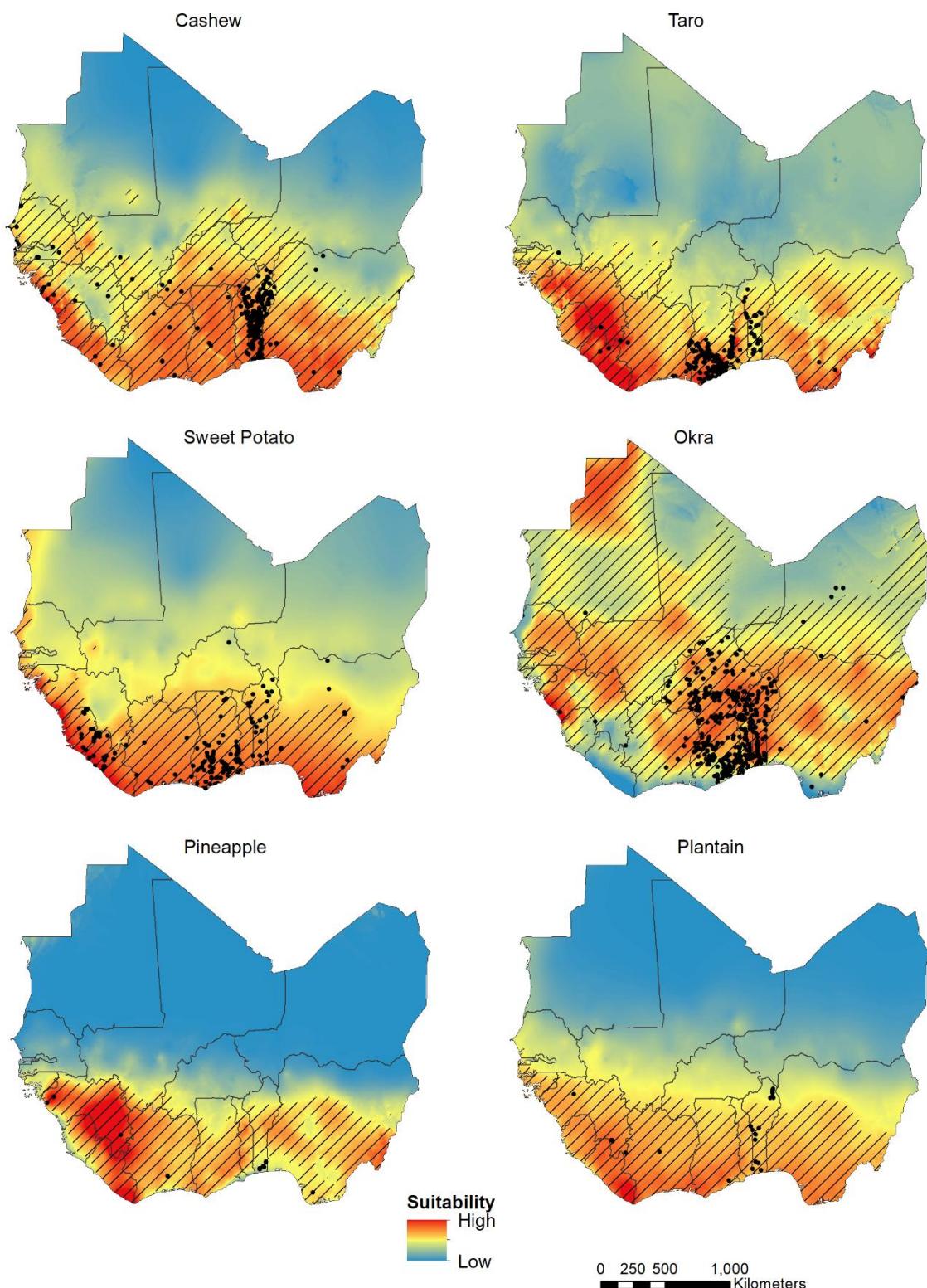
**Fig. 1. Map of West Africa as used in the study showing all the countries**



**Fig. 2. Spread of general circulation model (GCM) projections for annual mean temperature (x-axis) and annual precipitation (y-axis) are shown among each GCM for the year 2070 and RCP 8.5, for the 15 countries comprising continental West Africa; The selected ones are highlighted in red**

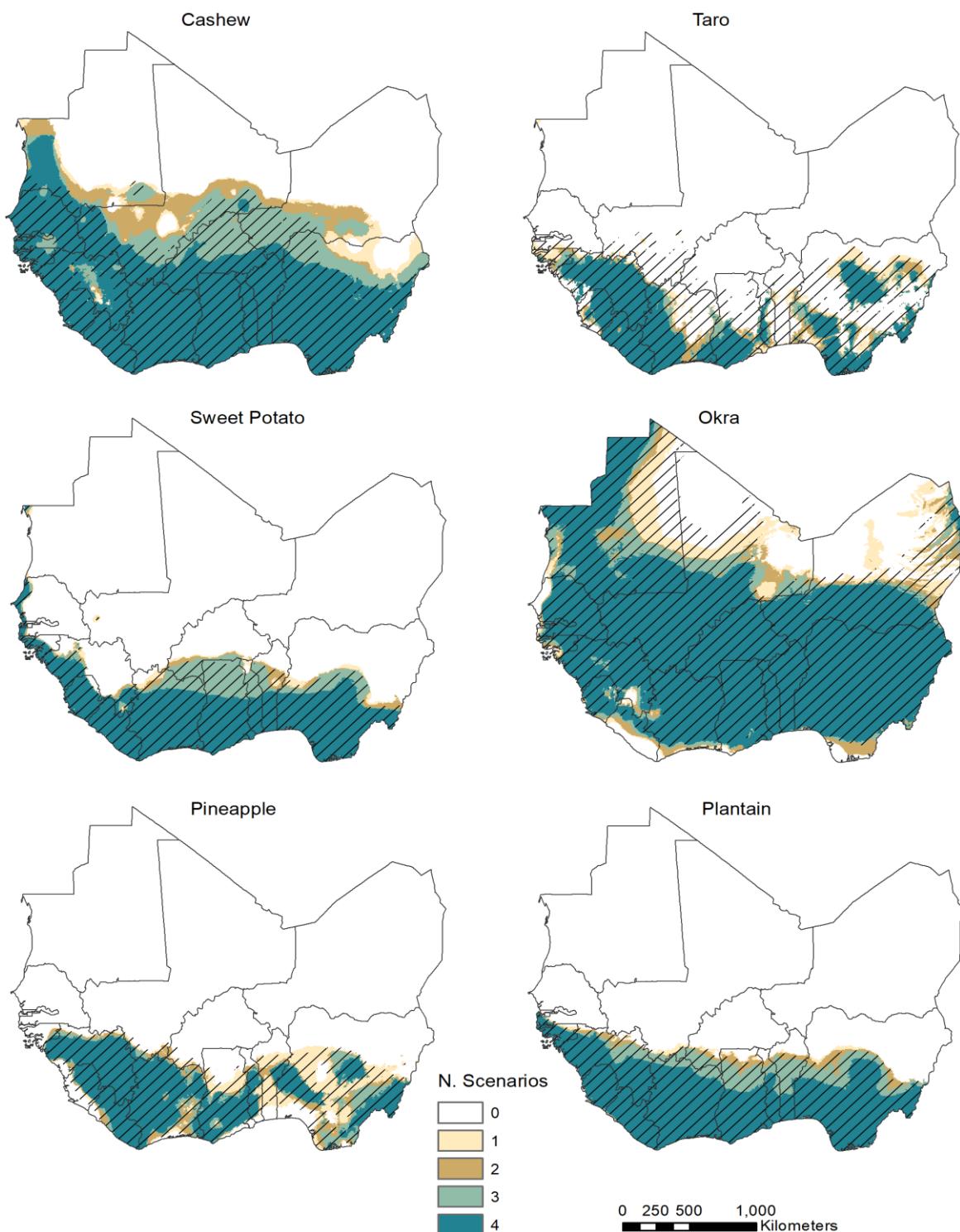


**Fig. 3. The methodology flowchart of the modelling study showing the key steps followed**



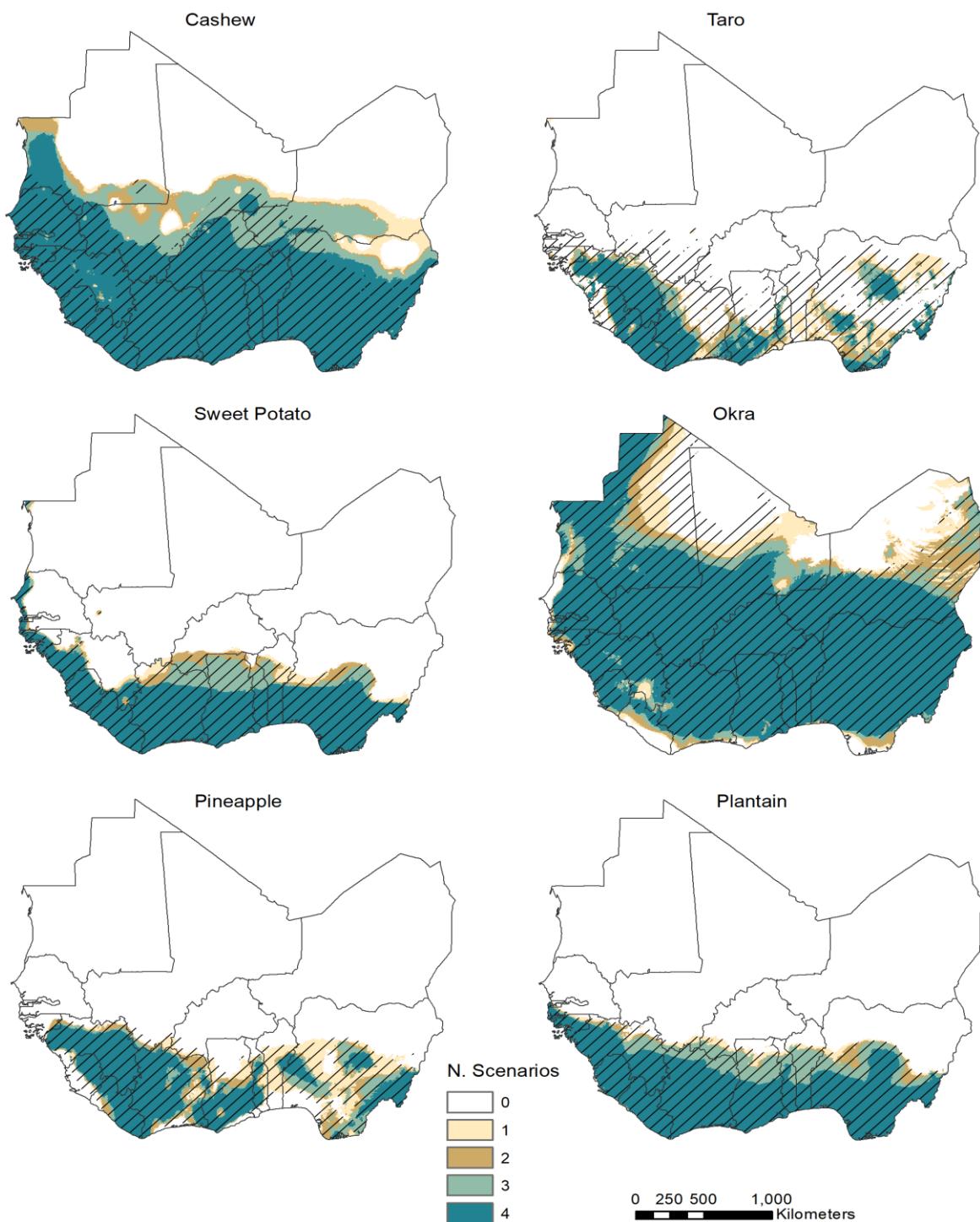
**Fig. 4. Potential consensus current habitat suitability (HS) of the six selected important horticultural crops in West Africa**

Identified using Maxent model under current (i.e. baseline 1960-1990) BIOCLIM climatic conditions). The dots represent the occurrence records downloaded from the Global Biodiversity Information Facility (GBIF, <http://data.gbif.org> accessed on June 2019)



**Fig. 5. Potential habitat suitability (HS) of the six selected important horticultural crops in West Africa**

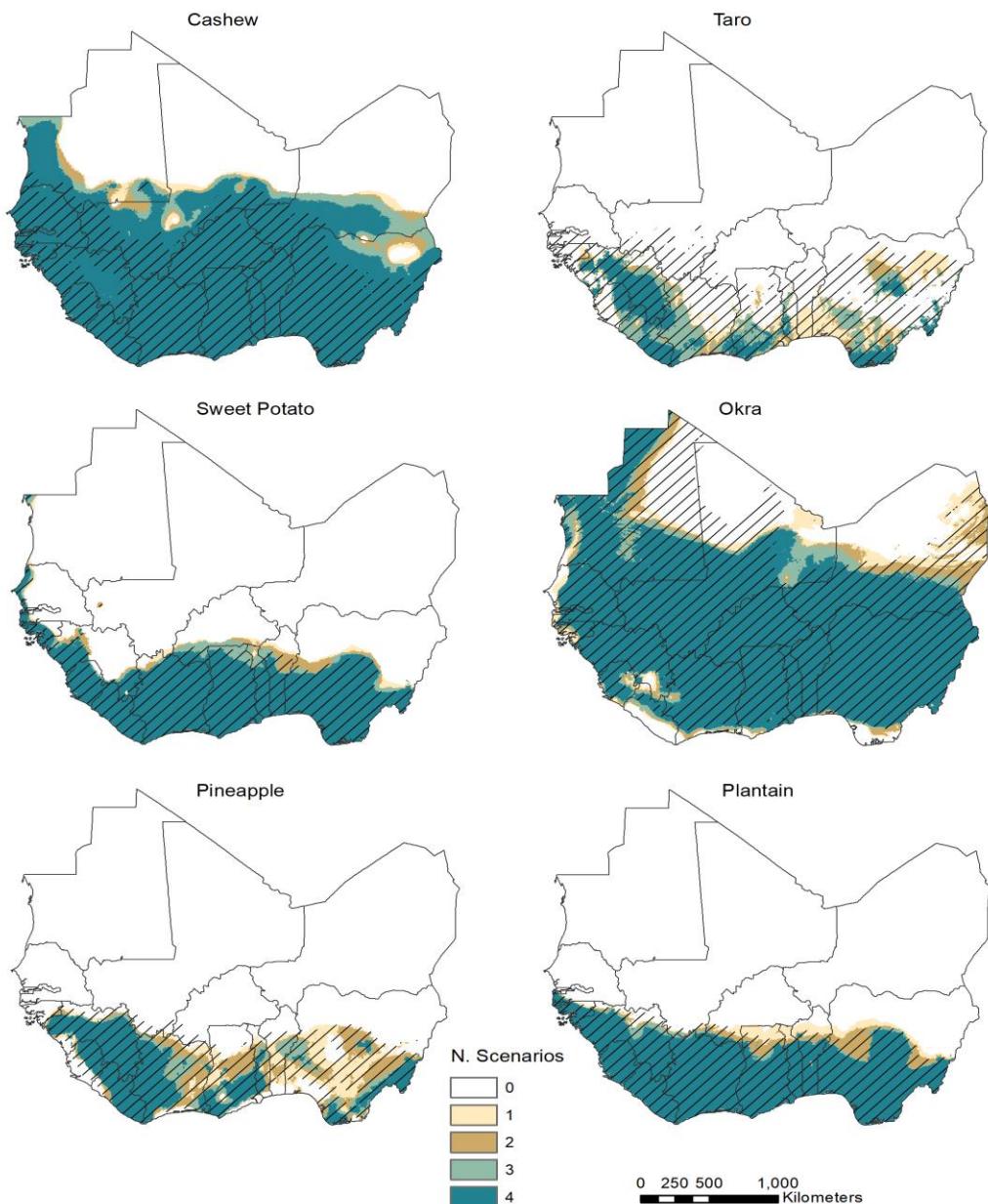
Identified using Maxent model for 2050s projections according to aggregated consensus of the four models used at Representative Concentration Pathway (RCP) 4.5 (i.e. the moderate greenhouse gas emission scenarios). N. Scenarios represents the four models which comprised: (1) Model for Interdisciplinary Research on Climate (MIROC5 for “warm/wet”), (2) The Community Earth System Model (CESM1-BGC for “average”), (3) Russian Institute for Numerical Mathematics Climate Model Version 4 (INM-CM5A for “hot/dry”), and (4) Institut Pierre Simon Laplace Model CM5A-MR (IPSL-CM5A-MR for “hot/dry”)



**Fig. 6. Potential habitat suitability (HS) of the six selected important horticultural crops in West Africa**

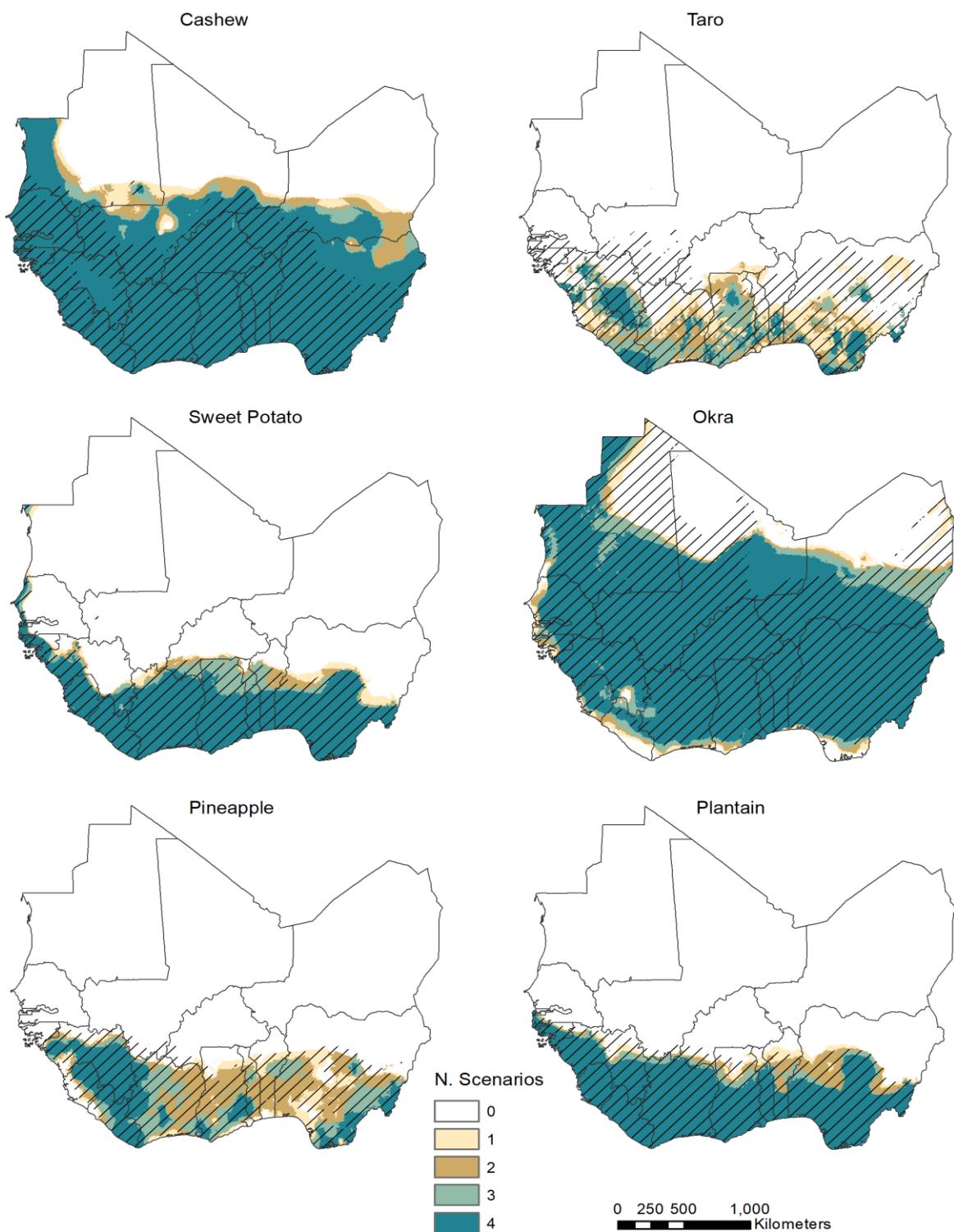
Identified using Maxent model for 2070s projections according to aggregated consensus of the four models used at Representative Concentration Pathway (RCP) 4.5 (i.e. the moderate greenhouse gas emission scenarios); N.

Scenarios represents the four models which comprised: (1) Model for Interdisciplinary Research on Climate (MIROC5 for “warm/wet”), (2) The Community Earth System Model (CESM1-BGC for “average”), (3) Russian Institute for Numerical Mathematics Climate Model Version 4 (INM-CM5A for “hot/dry”), and (4) Institut Pierre Simon Laplace Model CM5A-MR (IPSL-CM5A-MR for “hot/dry”)



**Fig. 7. Potential habitat suitability (HS) of the six selected important horticultural crops in West Africa. Identified using Maxent model for 2070s projections the aggregated consensus of the four models used at Representative Concentration Pathway (RCP) 8.5 (i.e. the maximum greenhouse gas emission scenarios)**

*N. Scenarios represents the four models which comprised: (1) Model for Interdisciplinary Research on Climate (MIROC5 for “warm/wet”), (2) The Community Earth System Model (CESM1-BGC for “average”), (3) Russian Institute for Numerical Mathematics Climate Model Version 4 (INM-CM5A for “hot/dry”), and (4) Institut Pierre Simon Laplace Model CM5A-MR (IPSL-CM5A-MR for “hot/dry”)*



**Fig. 8. Potential habitat suitability (HS) of the six selected important horticultural crops in West Africa. Identified using Maxent model for 2070s projections the aggregated consensus of the four models used at Representative Concentration Pathway (RCP) 8.5 (i.e. the maximum greenhouse gas emission scenarios)**

*N. Scenarios represents the four models which comprised: (1) Model for Interdisciplinary Research on Climate (MIROC5 for “warm/wet”), (2) The Community Earth System Model (CESM1-BGC for “average”), (3) Russian Institute for Numerical Mathematics Climate Model Version 4 (INM-CM5A for “hot/dry”), and (4) Institut Pierre Simon Laplace Model CM5A-MR (IPSL-CM5A-MR for “hot/dry”)*

## 5. CONCLUSION

This study serves as the first to assess future habitat suitability for horticultural crops produced under rain-fed conditions in West Africa. The maps of future suitability can help in identifying the likely key danger areas (i.e. mostly areas within the Sahel parts of the region) for the effective cultivation, planning, management, and resource utilization for horticultural crops. In addition, the model results may facilitate and encourage increase in capacity development for future climate change forecasting in developing regions like West Africa. As the climate continues to change and habitat suitability alters, it is essential to conduct studies on the possible effects of these changes on economically important plants such as horticultural crops. This work will provide a reference for future research on other crop species grown under natural conditions, which are vulnerable to the changing climate of this region.

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## COMPETING INTERESTS

Author has declared that no competing interests exist.

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