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Original article

Future expansion of small hive beetles, *Aethina tumida*, towards North Africa and South Europe based on temperature factors using maximum entropy algorithm

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ABSTRACT

Objectives: The small hive beetles (SHBs) cause dangerous damages to bee colonies in several countries. Some African countries represent the native land to these beetles. The SHBs are not well established in North Africa and South Europe (the closest land to the native countries). Therefore, this study aimed to model the current and future distribution of SHBs in Africa and South Europe utilizing temperature datasets.

Methods: A total of 250 occurrence data was incorporated in the study. Six temperature variables were used in the Maxent analysis to model the suitability of the study countries for the SHBs. Three climate models were used to estimate the future distribution of SHBs in 2050 and 2070, considering the lowest and the highest limits of the Shared Socio-economic Pathways (126 and 585).

Results and conclusions: The high performance of the used model was confirmed by analyzing omission/-commission rates as well as the area under curve. All future maps showed the potential expansion of SHBs towards the Northern parts of Africa and some parts in Europe. Such potential expansion was discussed in light of current distribution of SHBs. The study concluded that the SHBs can cause damages to bee colonies in new regions in Africa and Europe during the near future.

1. Introduction

Small hive beetles (SHBs), *Aethina tumida* Murray (Family: Nitidulidae), are native to some African countries and were described firstly by Murray (1867). It was recorded especially in Southern and Central African countries including Central African Republic (Lepissier, 1968), Uganda (Roberts, 1971), Congo Republic (Castagné, 1983), Botswana (Phokedi, 1985), Ghana (Adjare, 1990),

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Ethiopia, Eritrea, Kenya and Zimbabwe (Mostafa and Williams, 2000), South Africa, Guinea Bissau, Senegal, Angola, Nigeria, Tanzania, and Zambia (Neumann and Elzen, 2004). It was also recorded in other African countries within the endemic range including Madagascar (Rasolofoarivao et al., 2013), Benin and Burkina Faso (Neumann et al., 2016). Also, SHBs were recorded in other countries outside Africa including the USA during 1998 (Hood, 2000; Neumann and Elzen, 2004), Australia during 2002 (Neumann and Elzen, 2004), Mexico, Cuba, Jamaica, and Canada (Neumann et al., 2016). It is clear that SHBs are not spread in North Africa although the close distances and shared boundaries between countries; in addition to the similar genetic characteristics between bee subspecies in Africa (Abou-Shaara, 2019; Abou-Shaara et al., 2020). This suggests the impact of specific environmental conditions on the spread of SHBs especially temperature, considering the importance of temperature in climate change during the next few decades. Recently, SHBs were recorded in Porugal (Murilhas, 2004) and Italy (Mutinelli, 2014; Mutinelli et al., 2014; Palmeri et al., 2015) without wide establishments. Therefore, understanding the potential expansion of these beetles to other countries is very essential.

The SHBs cause serious damage to bee colonies especially in case of heavy infestations including feeding on stored honey and pollen in colonies as well as harming bee brood. The damages were estimated to be more than 3 million dollars in Florida state, USA in 1998 (Ellis et al., 2002a). Moreover, SHBs can serve as a vector to some honey bee diseases including *Paenibacillus larvae* (the cause of American foulbrood) (Schäfer et al., 2010; de Graaf et al., 2013), and viruses such as deformed wing virus and sacbrood virus (Eyer et al., 2009a; 2009b). The damages of SHBs to bee colonies in the native African countries are not high mostly due to the behaviors of the African bee subspecies against the beetles than the European bees in the invaded regions (Neumann and Elzen, 2004; Neumann and Härtel, 2004). It is clear the invasion of new environments with SHBs can cause undesired consequences on apiculture.

In fact, the effects of climate change on honey bees and their pests are a major concern especially during the next years (Le Conte and Navajas, 2008; Abou-Shaara, 2016). The increase in temperature is the key phenomenon of climate changes (Yoruk and Sahinler, 2013; Abou-Shaara, 2016). It is expected that the distribution of bee diseases and pests as well as plant pollination will be impacted by climate changes (Le Conte and Navajas, 2008; Hegland et al., 2009; Rader et al., 2013; Abou-Shaara, 2016). Recently, some bee pests succeeded to invade new environments including the Asian hornets, *Vespa velutina* (Hymenoptera: Vespidae) (López et al., 2011; Monceau et al., 2014) and small hive beetles (Murilhas, 2004; Mutinelli, 2014; Mutinelli et al., 2014; Palmeri et al., 2015). Thus, temperature datasets can help in understanding the potential effects of climate change on the distribution of bee pests. The present study aimed to model the current and future distribution of SHBs in Africa and some European countries to understand the potential expansion of these beetles towards the North. Thus, temperature datasets were primarily utilized in this study in combination with MaxEnt to perform the analysis. Indeed, climatic suitability models can be utilized to predict the geographical distribution of species (Guisan and Thuiller, 2005) including MaxEnt (Wei et al., 2018).

2. Methods

2.1. Occurrence data

It was a challenge to find sufficient number of occurrence records of small hive beetles (SHBs) in Africa from online resources. SHBs are native to Central and Southern African countries (Neumann and Elzen, 2004; Neumann and Ellis, 2008; Neumann et al., 2016). Therefore, available occurrence records were initially downloaded from the Global Biological Information Facility (GBIF.org, 2020). The repeated records were removed, and then additional records were proposed for the native countries with help from Google earth to obtain accurate coordinates. From each country 15 occurrences were used with a total of 250. The study was limited to cover Africa and South Europe, representing the endemic range of SHBs and the closest countries.

2.2. Temperature data

Changes in temperature represent the main phenomenon of future climate. Thus, variables related to temperature from WorldClim (www.worldclim.org) with a spatial resolution of about 5 km^2 were utilized in the analysis. Six temperature variables were incorporated in the study after removing variables with known spatial artifacts and discontinuous spatial anomalies (bio8: mean temperature of wettest quarter and bio9: mean temperature of driest quarter) (Escobar et al., 2014; Samy et al., 2016; Alkishe et al., 2017) or those derived from the main variables. The six variables were: annual mean temperature (bio1), mean diurnal range (bio2), maximum temperature of warmest month (bio5), minimum temperature of coldest month (bio6), mean temperature of warmest quarter (bio10), and mean temperature of coldest quarter (bio11). These variables for the period from 1970 to 2000 (WorldClim v2.1 released in January 2020) were used to study distribution of SHBs under current temperature conditions.

2.3. Future temperature data

The future data used in this study were for two future time points 2050 (average from 2041 to 2060) and 2070 (average from 2061 to 2080) and from three climate models: MRI-ESM2-0, BCC-CSM2-MR, and CNRM-CM6-1 from the Meteorological Research Institute, the Beijing Climate Center, and National Centre for Meteorological Research, respectively. Also, the lowest and the highest limits of the Shared Socio-economic Pathways (SSP126 and SSP585) of these climate models were analyzed in the study to better prediction of future conditions. Currently the Shared Socioeconomic Pathways (SSPs) are used by the Intergovernmental Panel on Climate Change (IPCC) in the 6th Assessment Report. These data were obtained from the Coupled Model Intercomparison Project Phase 6 (CMIP6) (Eyring et al., 2016). To reduce the number of maps and to facility the explanation of the results, only two maps for each time point (one for SSP126 and the other one for SSP585) as an average of the three climate models were presented.

2.4. Maximum entropy modeling

Current and future distribution of SHBs in Africa and South Europe was analyzed using the maximum entropy modeling in Maxent v 3.4.1 (Phillips et al., 2020). The model used 25% of presence records as random test points. The run conditions included 10,184 background and presence points used to determine the Maxent distribution, algorithm terminated after 500 iterations (33 s), and linear/quadratic/product: 0.050, categorical: 0.250, threshold: 1.000, and hinge: 0.500 as the regularization values. The model maps were reclassified using the ArcGIS 10.5 into four classes: 0–0.01, 0.01–1, 1–20, and 20–100 for rare suitable, moderate suitable, high suitable, and very high suitable, respectively.

2.5. Model performance

The model performance was assessed using Maxent v 3.4.1 (Phillips et al., 2020). The analysis of omission/commission rates was used to evaluate the model. The function of the cumulative threshold (the omission rate and predicted area) was also analyzed. The area under curve (AUC) which can give an indication about of the model performance was identified using the receiver operating characteristic (ROC). Moreover, temperature variables used in the model were analyzed in regard to their contribution percentages in the model and their response curves.

3. Results

3.1. Model performance

It is clear from Fig. 1 that the omission rate is close to the predicted omission for the training presence records and the test records. The area under the curve (AUC) is 0.81 for the training

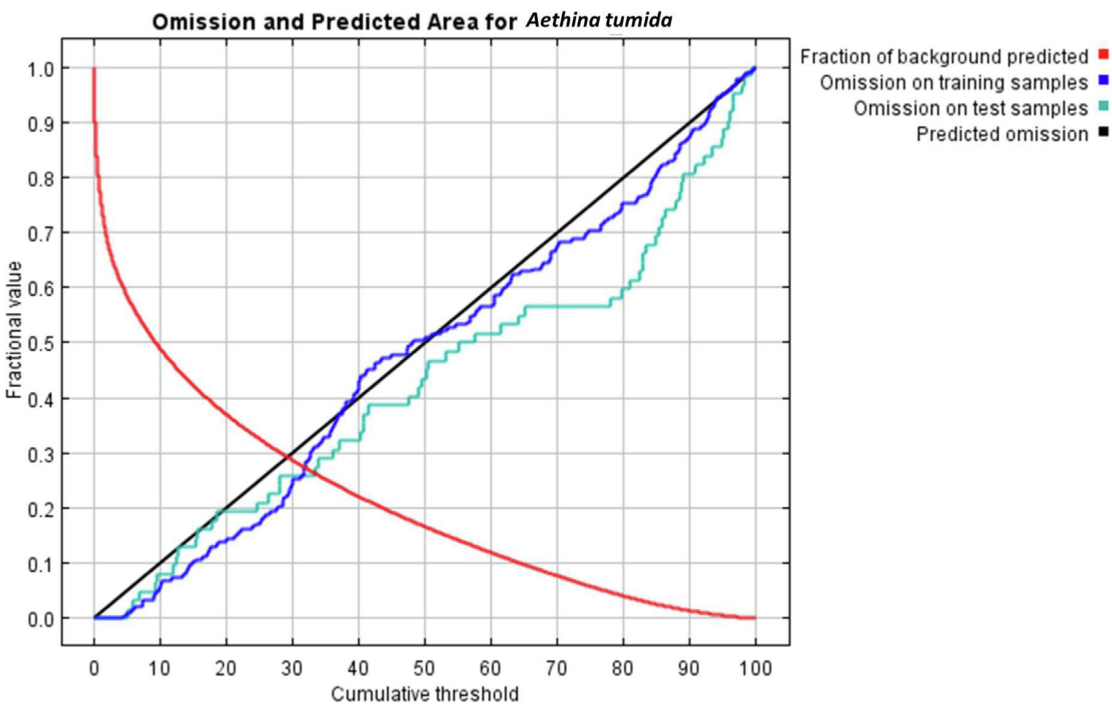

Fig. 1. The omission rate for training and test samples, and predicted area as a function of the cumulative threshold.

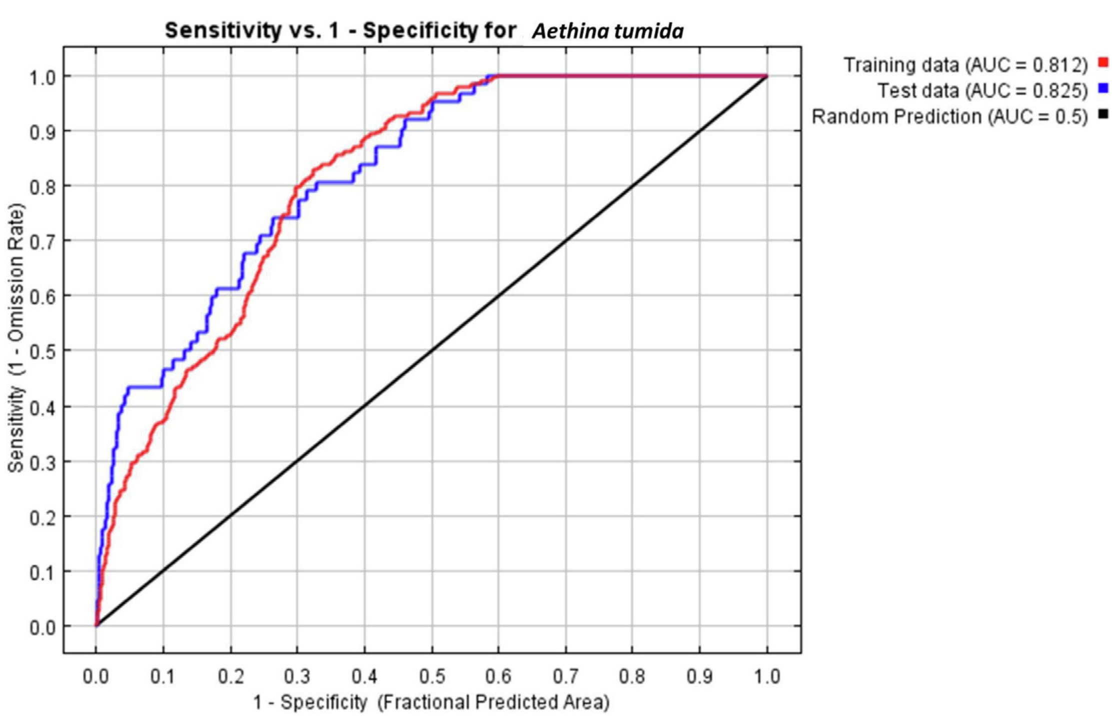

Fig. 2. The curve of receiver operating characteristic for the training and test data.

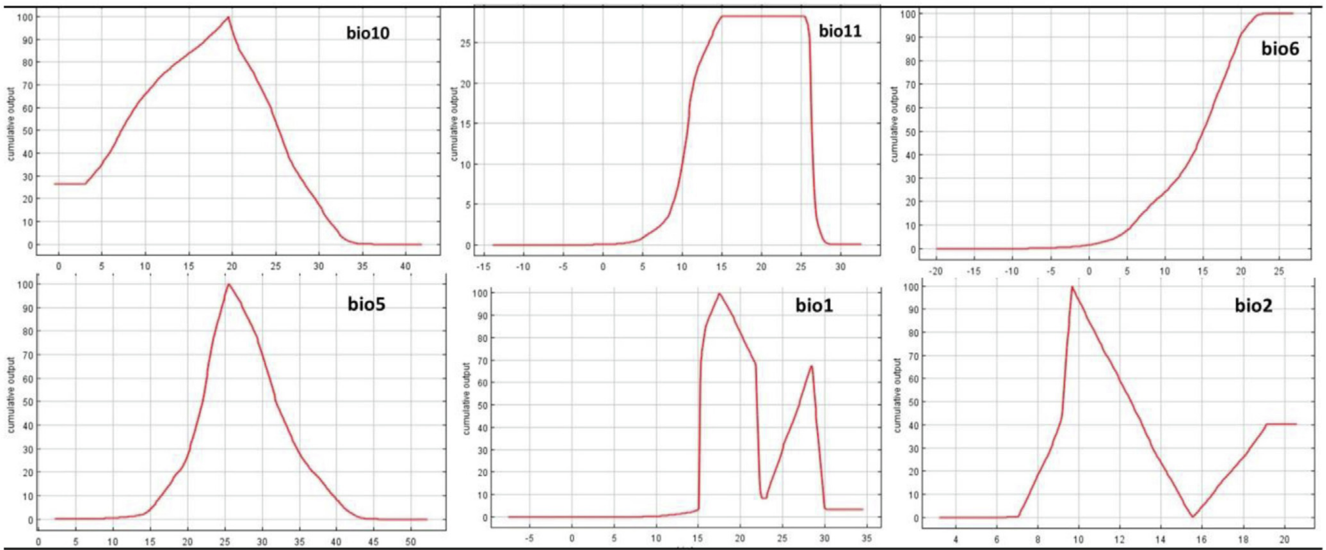

Fig. 3. Response curves of the variables. Annual mean temperature (bio1), mean diurnal range (bio2), max temperature of warmest month (bio5), minimum temperature of coldest month (bio6), mean temperature of warmest quarter (bio10), and mean temperature of coldest quarter (bio11).

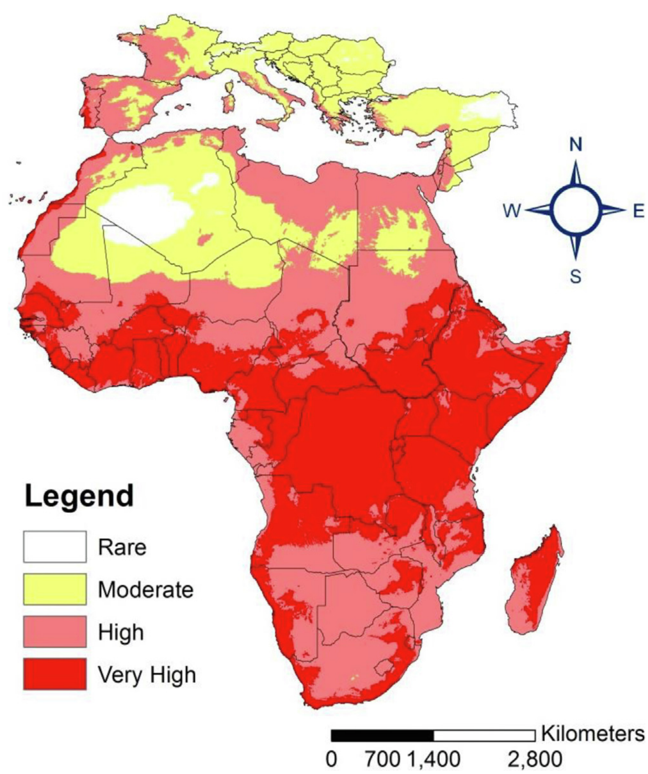

Fig. 4. Distribution of the Small Hive Beetles under current climate conditions in Africa and South Europe.

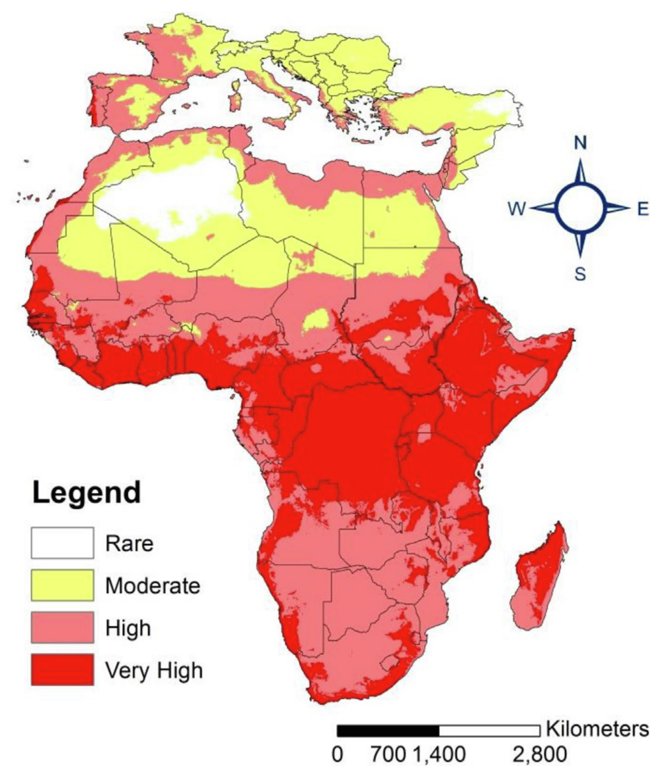

Fig. 5. Distribution of the Small Hive Beetles under future climate conditions during 2050 (SSP 126). This map presents the average of three climate models (MRI-ESM2-0, BCC-CSM2-MR and CNRM-CM6-1).

data and 0.82 for the test data based on the curve of receiver operating characteristic for the training and the test data (Fig. 2).

The contributions of the variables in the model were 29.9, 26.2, 22.6, 11.3, 5.3, and 4.7% for bio10, bio11, bio6, bio5, bio1 and bio2, respectively. Therefore, mean temperature of warmest quarter (bio10), and mean temperature of coldest quarter (bio11), minimum temperature of coldest month (bio6) had the highest contribution in the model among the used temperature variables. The response curves (Fig. 3) of the used variables showed specific suitable ranges of SHBs to each variable. It is obvious that these ranges tended towards moderate conditions above 15℃.

3.2. Current distribution

The map of current distribution of SHBs (Fig. 4) shows the occurrence of these beetles in most African countries. This map suggests the potential distribution of SHBs in North Africa especially Egypt, Libya, Tunisia, Morocco and Northern parts of Algeria and some parts in Europe especially Portugal, Spain, France and Italy. The majority of European countries and Algeria considered as moderately suitable for SHBs. The rare occurrence was expected mainly in West Algeria.

3.3. Future distribution (2050)

The maps based on the low limit (SSP 126) and the high limit (SSP 585) for 2050 show approximately the same expectation of SHBs distribution (Figs. 5 and 6). The majority of North Africa and South Europe classified as moderately suitable for SHBs. The coastal regions in North African countries were classified as highly suitable for SHBs. Also, some European countries especially Portugal, Spain, France and Italy as well as some islands in the Mediterranean Sea were considered as highly suitable for SHBs. The native countries of SHBs were considered as very high or high suitable.

3.4. Future distribution (2070)

The map based on the low limit of SSP126 for 2070 (Fig. 7) shows approximately similar distribution to SHBs during 2050 in Africa and South Europe. Still Northern parts of Africa beside Portugal, Spain, France and Italy are high suitable for SHBs. Also, the moderately and rarely suitable locations showed the same trend to 2050. The map based on the high limit of SSP585 for 2070 (Fig. 8) shows some differences than 2050 and the low limit of 2070 especially in locations classified as moderate or rare suitable for SHBs. The moderate locations for SHBs extended to contain more African countries while the locations classified as rare suitable extended to contain more area in Algeria.

4. Discussion

4.1. Model performanc

The omission rate was close to the predicted omission for the training presence records and the test records. Thus, the model used in the present study showed high performance. Moreover,

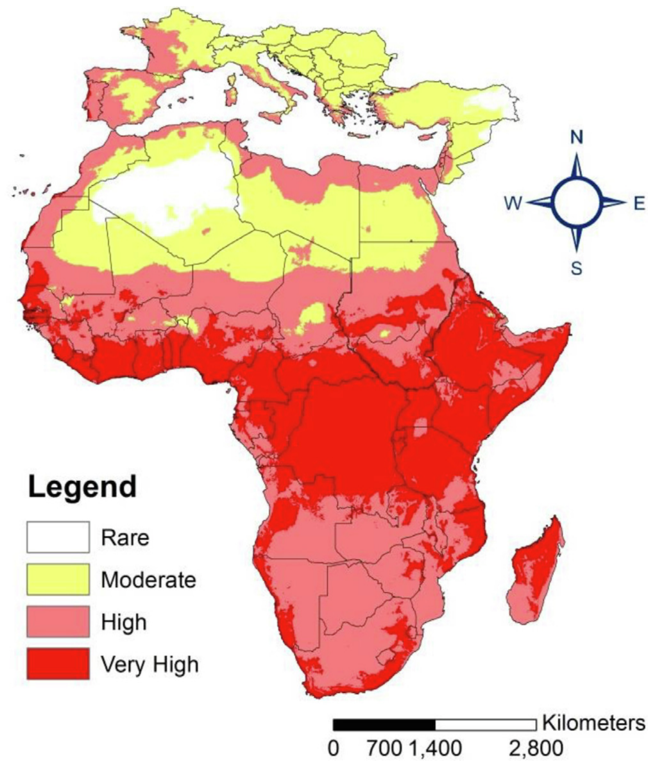

Fig. 7. Distribution of the Small Hive Beetles under future climate conditions during 2070 (SSP 126). This map presents the average of three climate models (MRI-ESM2-0, BCC-CSM2-MR and CNRM-CM6-1).

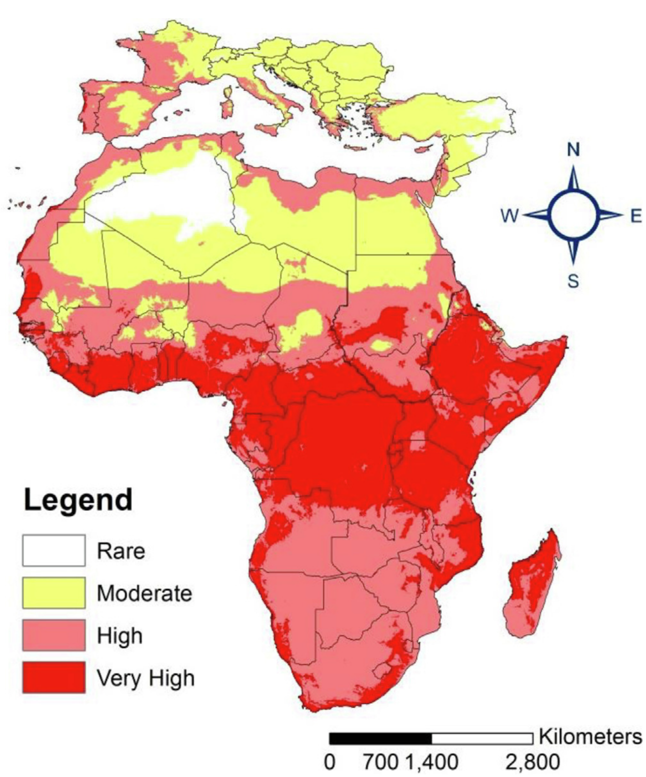

Fig. 6. Distribution of the Small Hive Beetles under future climate conditions during 2050 (SSP 585). This map presents the average of three climate models (MRI-ESM2-0, BCC-CSM2-MR and CNRM-CM6-1).

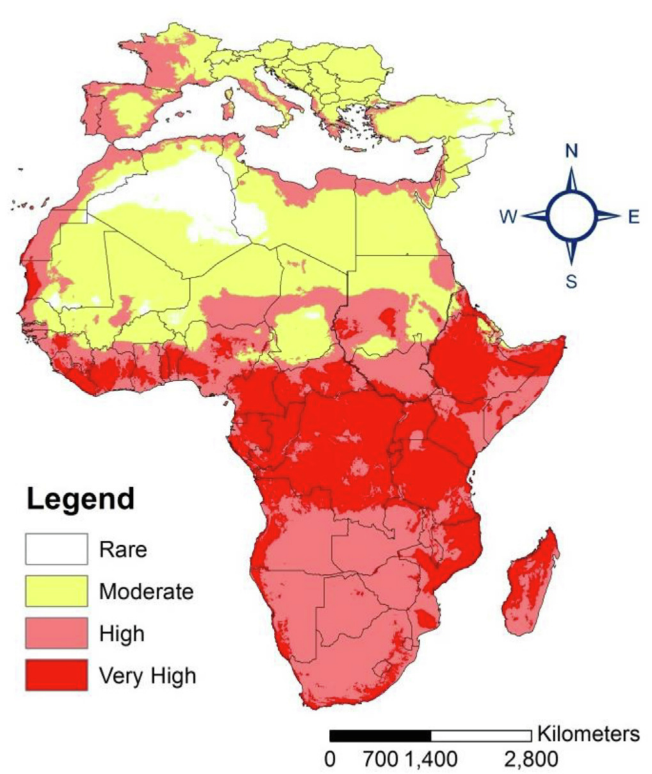

Fig. 8. Distribution of the Small Hive Beetles under future climate conditions during 2070 (SSP 585). This map presents the average of three climate models (MRI-ESM2-0, BCC-CSM2-MR and CNRM-CM6-1).

the area under the curve (AUC) was 0.81 for the training data and 0.82 for the test data, and these values were close to 1 with difference of 0.19 and 0.18. According to Mulieri and Patitucci (2019), values more than 0.75 indicate to a very good fit of the used model. Indeed, the development of SHBs is impacted by temperature (Neumann et al., 2001; Neumann and Elzen, 2004). Accordingly, mean temperature of warmest and coldest quarter beside minimum temperature of coldest month had the highest contribution in the model among the used temperature variables with temperature above 15C.

4.2. Current distribution

The map of the current distribution reflected the real occurrence of SHBs within the endemic range in Africa. In addition to the endemic countries, parts in North Africa especially Egypt, Libya, Tunisia, Morocco and Northern parts of Algeria and some parts in Europe especially Portugal, Spain, France and Italy were suggested to be invaded with SHBs. Thus, specific precautions by the responsible agencies at these countries should be taken to prevent the potential invasion. The SHBs were recorded in Itay-Al-Baroud district in Egypt during 2000 (Mostafa and Williams, 2000) without establishment in Egypt (El-Niweiri et al., 2008; Neumann et al., 2016). The survey by Hassan and Neumann (2008) in 11 Egyptian districts showed the absence of SHBs. Also, a survey from 2013 to 2015 showed the absence of these beetles as a pest to bee colonies in the Arabian countries including Egypt (Al-Ghamdi et al., 2016). Moreover, the study by Abou-Shaara et al. (2018) showed the presence of some Nitidulid beetles in Egypt that can feed on bee pollens but no SHBs were recorded. In fact, no SHBs were detected by beekeepers in Egypt.

In Portugal, SHBs were detected in a shipment of queens in 2004 and the establishment of SHBs was prevented (Murilhas, 2004; Neumann and Ellis, 2008; Valério da Silva, 2014). SHBs were also found in Calabria, Italy in September 2014 (Mutinelli et al., 2014; Palmeri et al., 2015). The reports showed confirmed infestations at some apiaries but the wide establishment of SHBs in Italy was not confirmed. Such occasional invasions support the present study as some European countries were classified as suitable for SHBs. The situation of SHBs need to be assessed from time to another especially SHBs have alternative food sources and can survive outside of bee colonies (Neumann et al., 2016). In fact, the Nitidulid beetles have various food types including fruits either fresh or dried beside plant juices (Lin et al., 1992; Fadamiro et al., 1998; Eischenet al., 1999; Smart and Blight, 2000; Wolff et al., 2001; Ellis et al., 2002a; Neumann et al., 2016). Indeed, these alternative foods are not good for the reproduction of SHBs if compared with bee products (Ellis et al., 2002a).

4.3. Future distribution

In fact, all maps showed the potential expansion of SHBs towards the Northern parts of Africa and some parts in Europe (moderate to high suitable). The high suitable regions based on all future model maps included coastal regions in Africa and some European countries: Portugal, Spain, France and Italy as well as some islands in the Mediterranean Sea. The increase in the moderate/rare suitable locations for SHBs in the map based on the high limit of SSP585 for 2070 than 2050 and the low limit of 2070 can be explained by the potential increase in temperature during 2070. In fact, the spread of the beetles to invade other locations is supported by two points: 1) the preference of SHBs to flight to another locations ignoring neighboring bee colonies after emergence from the soil (Neumann et al., 2012), and 2) transportation of bee packages and equipment from location to another beside migratory beekeeping (Neumann and Elzen, 2004; Gordon et al., 2014; Neumann et al., 2016). Currently, there are some control options available against SHBs (Ellis et al., 2002b; Neumann et al., 2016; Abou-Shaara and Staron, 2019). However, efforts to prevent the invasion of new environments with SHBs should be considered.

5. Conclusion

This is approximately the first study to use the Shared Socioeconomic Pathways to predict the effects of climate change on the distribution of SHBs. So, the model used in the present study focused on temperature datasets; especially temperature change is the main phenomenon in future climate. The study showed the potential movements of SHBs towards some Northern parts in Africa (especially coastal regions) and some countries in Europe (especially Portugal, Spain, France and Italy). The recent records of SHBs in some parts in Europe were in line with the present study. The invasion of SHBs to new countries can cause serious damages to the beekeeping sectors, causing economic damages. Thus, the responsible authorities should take some steps to prevent the invasion of these beetles to their countries including the development of early monitoring systems for SHBs.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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