Original article

Modeling the potential distribution of the predator of honey bees, *Palarus latifrons*, in the Arabian deserts using Maxent and GIS

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ABSTRACT

Objectives: The species *Palarus latifrons* (bee pirates) has been recorded in Saudi Arabia as an invasive species. This pest can destroy honey bee colonies under certain conditions. The origin of this species in Africa and it has a good ability to adapt to desert conditions. Studies on this species are very few but its current distribution in the Arabian deserts is mainly in the Arabian Gulf countries. This study presents maps for the possible expansion of this species to invade other desert areas in the Arabian countries' under current and near-future conditions (2030).
Methods: This pest is a solitary insect with high activity during summer. It is hypothesized that summer conditions and especially temperature are the limiting factor for its distribution in the deserts. The analysis depended on generating maps based on temperatures during summer and based on two bioclimatic factors. Maxent and the geographical information system (GIS) were used to perform the analysis.
Results and conclusions: All maps showed the high ability of this pest to spread in the Gulf countries. In North Africa: south Egypt and Libya, and some parts of Algeria showed suitability for *Palarus*. The invasion of this pest towards North Africa can happen mostly due to trading activities with Gulf countries especially materials containing soil. Continues monitoring for the activity of *Palarus* in the risk areas is highly advised.

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1. Introduction

Several honey bee, *Apis mellifera* L., pests have been recorded in various parts of the world. Some of these pests have a specific geographical range including the large hive beetles in Africa (Oldroyd and Allsopp, 2017), and the parasitic flies *Senotainia tricuspis* in the Mediterranean region (Haddad et al., 2015). Part of such pests have succeeded to invade new regions outside their original areas such as small hive beetles from Africa to other countries including the USA (Neumann et al., 2016), the Asian hornets, *Vespa velutina* from Asia to some European countries (Haxaire et al., 2006; López et al., 2011; Grosso-Silva and Maia, 2012; Demichelis et al., 2014; Monceau et al., 2014), and bee pirates especially *Palarus latifrons* Kohl from Africa to Saudi Arabia (Al-Ghamdi, 2004). In general, genus *Palarus* occurs in different regions including Europe

(Gayubo et al., 1992; Nemkov, 2005). This specific species of bee pirates is originally from Africa (Mally, 1908; Brauns, 1912; Mungai et al., 2009) including Sudan (El-Niweiri and Satti, 2008) but it has been recorded in Saudi Arabia. During a survey in 1989, *P. latifrons*, was found in Jizan, Al-Qunfudaha, Thahma, and Jeddah (Al-Ghamdi, 2004) and have been confirmed in Saudi Arabia in other studies (Gadallah and Assery, 2004; Gadallah et al., 2013). It seems that this species has adapted to harsh desert conditions. So, it is expected that this species will invade new areas in the Gulf countries and North Africa. Indeed, the Arabian countries contain vast desert areas with specific environmental conditions.

The bee pirates, *P. latifrons*, attack bee colonies to prey upon adult honey bee workers (Mally, 1908; Al-Ghamdi, 2004). High numbers of *P. latifrons* can be found in front of beehives (Clauss, 1983). The presence of bee pirates close to the hives prevents the normal foraging activity of honey bees (Mally, 1908; Guy, 1972; Mungai et al., 2009). The damage to bee colonies is mostly high during summer when high numbers of this pest have existed. The females carry the bee workers to their nests to feed their larvae. This pest belongs to digger wasps and typically dig burrows in the soil especially sandy soils (Mally, 1908; Smith, 1961). The

activity of *Palarus* extends from spring up to autumn, but the highest activity is during the summer. Therefore, it could be said that summer conditions at deserts are a limiting factor for the activity and distribution of this pest. Indeed, the temperature is highly varied from one desert location to another. So, maps based on temperatures are expected to be effective methods to evaluate the potential distribution of this pest under different climatic conditions.

The spread of some species and pests from Gulf countries to north Africa or vice versa is possible; especially through Egypt thanks to its geographical location between Africa and Asia. A good example of the spread of an invasive species from Gulf countries to Africa is the invasion of the dwarf honey bees, *Apis florea*, to Egypt. This bee species is adapted to harsh conditions in the Gulf countries (Al-Kahtani and Taha, 2014; Taha et al., 2016) unlike the environmental conditions in its locations in other Asian countries (Ruttner, 1988; Rinderer et al., 1995; Otis, 1996; Hepburn and Radloff, 2011; Ilyasov et al., 2020). Recently, it has been recorded in some parts of Egypt (Shebl, 2017).

Understanding species distribution in different geographical regions can be achieved using species distribution software such as Maxent beside geographical information system (GIS) (Abou-Shaara, 2019; Hosni et al., 2020; Jamal et al., 2021). Indeed, various environmental variables for current and future conditions have existed on the Worldclim website which is a good online source (Hijmans et al. 2005). It is anticipated that species distribution and beekeeping will be impacted by future conditions especially temperature (Le Conte and Navajas, 2008; Yoruk and Sahinler, 2013; Abou-Shaara, 2016; Jamal et al., 2021). The objective of this study was to analyze the potential spread of bee pirates (*P. latifrons* from Saudi Arabia) in the Arabian deserts undercurrent and near-future conditions using distribution maps utilizing Maxent and GIS.

2. Materials and methods

2.1. Occurrence of bee pirates in Saudi Arabia

The data about the occurrence of bee pirates (*Palarus latifrons*) in the Arabian deserts are only available from Saudi Arabia. Therefore, the locations of the occurrence records were assigned based on previous publications (Al-Ghamdi, 2004). Fig. 1 shows the Arabian deserts in the Gulf countries and North Africa and the locations of the 39 records in Saudi Arabia.

2.2. Summer conditions

The climate website of worldclim.org (WorldClim version 2.1 climate data, released January 2020) was used to obtain the environmental variables. The temperature during summer (period from June to August) is a limiting factor for the activity of bee pirates in the deserts. Also, these factors varied greatly from one desert area to another. Therefore, minimum, average, and maximum temperature datasets for June, July, and August were used in the analysis. These environmental datasets were downloaded for current conditions and near-future conditions (from 2021 to 2040, the average for 2030) with about 5 km^2 as a spatial resolution. The future datasets were downloaded from downscaled climate data from the Coupled Model Intercomparison Project Phase 6 (CMIP6) for the climate model of BCC-CSM2-MR using Shared Socio-economic Pathway 245 (ssp245).

2.3. Bioclimatic variables

Two variables related to summer conditions in the deserts: Maximum temperature of the warmest month (MTWM), and mean temperature of the warmest quarter (MTWQ) were downloaded for current and near-future conditions from worldclim.org as described previously.

2.4. Steps of the analysis

Maps were established for minimum, average, and maximum temperatures during June, July, and August using Maxent v 3.4.1 (Phillips et al., 2020;). Then, the obtained maps were combined using GIS 10.5 to obtain one map as an average for current conditions, and another map for future conditions (using raster calculator tool). The same steps were used with the two bioclimatic variables. The general steps of the analysis are shown in Fig. 2. The Maxent run was done using cumulative as output considering 25% of the data as test data. The map legend was classified in the ArcGIS 10.5 into four distinct classes: Very low (0–10), Low (10–
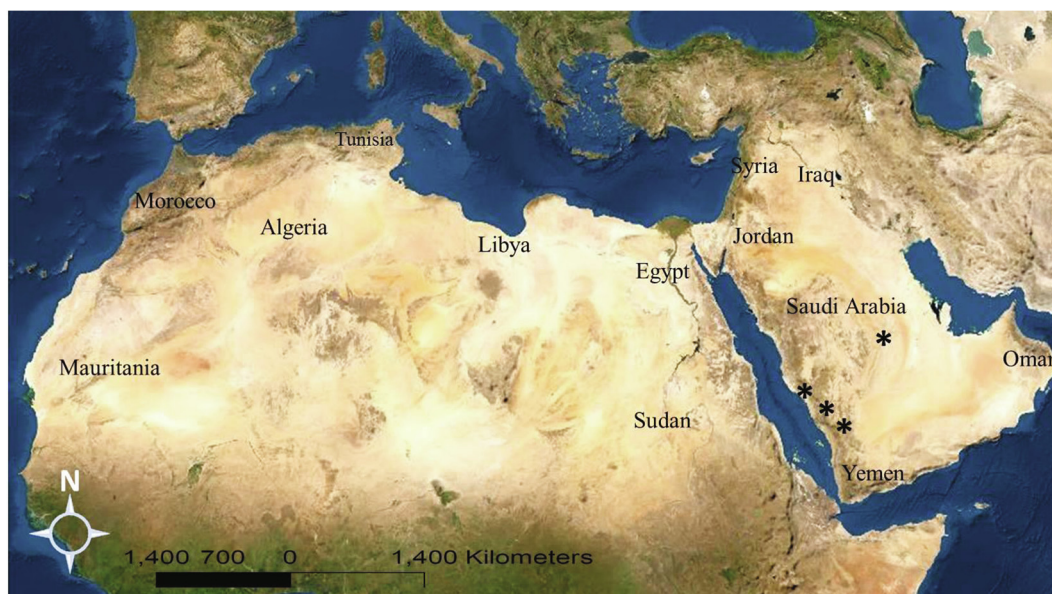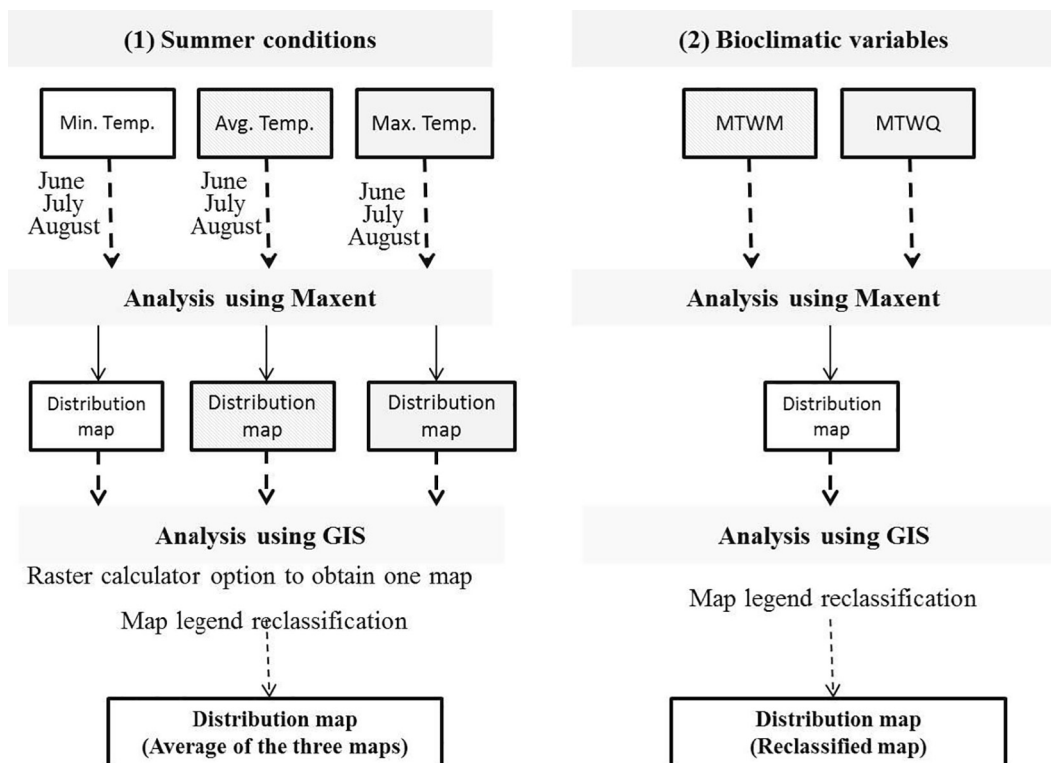

Fig. 1. The Arabian deserts, and the locations (*) for the occurrence records of *Palarus latifrons* in Saudi Arabia (Google Erath map).

Fig. 2. Steps used to obtain species distribution maps using Maxent and GIS. These steps were used to obtain maps for current and near future conditions. MTWM: Maximum temperature of the warmest month, and MTWQ: Mean temperature of the warmest quarter.

20), Suitable (20–50), and High Suitable (50–100). The cumulative output of maxent considers value more than 20 as suitable (Phillips, 2017).

2.5. Evaluation

The contribution of each dataset in the obtained maps was calculated and presented. Also, the performance of the model was evaluated using the area under the curve (DeLong et al., 1988) for monthly datasets from the jackknife test and test/training data from the receiver operating characteristic curve of the model maps.

3. Results

3.1. Current distribution

The dataset of June had the highest contribution in all maps (Table 1). The contribution of June, July, and August in the map as an average for the three maps (minimum, average, and maximum temperatures) was 62.9, 20, and 17.1%, respectively. The values of area under the curve ranged from 0.69 to 0.92 and were higher than 0.75 for most datasets. The values for training and test data were 0.91 ± 0.007 and 0.82 ± 0.01, respectively (Table 2).

The model map based on summer conditions (Fig. 3) shows that the highly suitable and suitable areas for *P. latifrons* are concentrated in the Gulf countries: Saudi Arabia, Emirates, Oman, and Yemen. Some parts of Iraq and Kuwait were considered as low suitable for *P. latifrons.* In North Africa, suitable areas are located in southern Egypt and some parts of Algeria while the low suitable areas are located in southern Egypt, south Libya and some parts of Algeria. The coastal areas in all countries showed very low suitability for bee pirates. So, beekeeping in such regions is not expected to suffer from the attack of this pest unlike those in desert areas.

The maximum temperature of the warmest month and mean temperature of the warmest quarter contributed to the model map by 99.7 and 0.3%, respectively. The area under the curve was 0.937 for training data, and 0.716 ± 0.091 for test data. The map based on the two climatic factors (Fig. 4) shows the very high suitability of all Gulf countries for *P. latifrons.* Unlike the previous map, Iraq and Kuwait were considered as very high suitable areas for this pest. In North Africa, some areas in south Egypt were considered as low suitable while vast areas in Algeria were considered as suitable/very suitable for this pest. This map confirms that northern parts of the Arabian countries are not suitable for *P. latifrons.*

Table 1
Contribution percentages of monthly temperature datasets in the model maps.

| Months	Maps			Average contribution ± S.D.
	Minimum temperature	Average temperature	Maximum temperature	
June	61.1	71.1	56.5	62.9 ± 7.46
July	17.6	25.7	16.7	20 ± 4.95
August	21.3	3.2	26.8	17.1 ± 12.34

Table 2
Values of area under the curve for monthly datasets from the jackknife test and for test/training data from the receiver operating characteristic curve of the model maps.

Datasets	Maps			Average value ± S.D.
	Minimum temperature	Average temperature	Maximum temperature	
June	0.82	0.77	0.67	0.75 ± 0.07
July	0.79	0.76	0.76	0.77 ± 0.01
August	0.73	0.69	0.74	0.72 ± 0.02
Training data	0.921	0.907	0.914	0.91 ± 0.007
Test data	0.835	0.813	0.841	0.82 ± 0.01
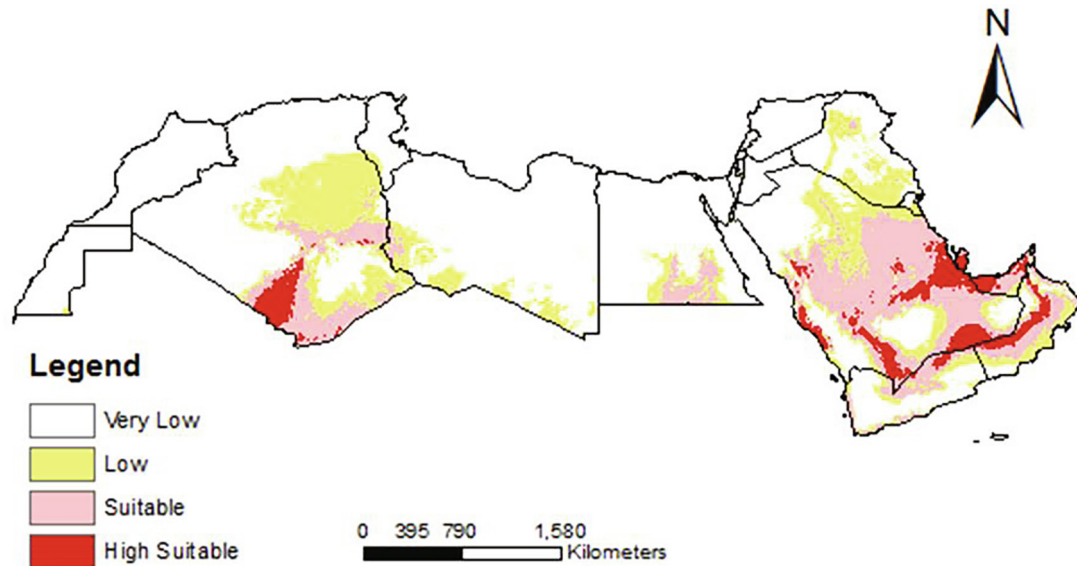
Fig. 3. Potential distribution of *Palarus latifrons* under current conditions based on the average of three maps (minimum, average and maximum temperature) during summer (June, July and August).
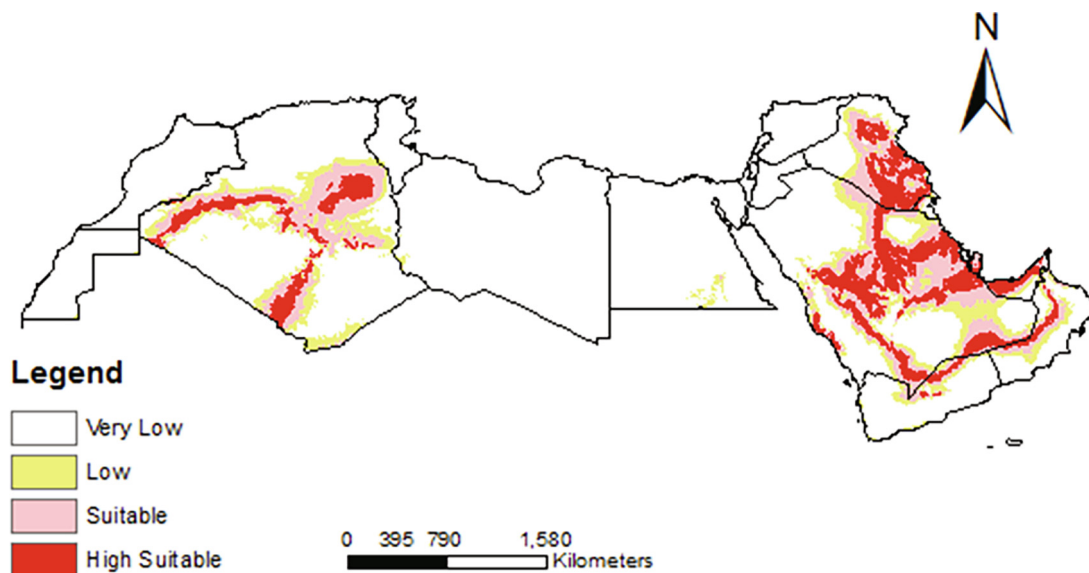
Fig. 4. Potential distribution of *Palarus latifrons* under current conditions based on two environmental variables (MTWM: Maximum temperature of the warmest month, and MTWQ: Mean temperature of the warmest quarter).

3.2. Distribution during the near future

The datasets of June had the highest contribution in three maps for summer conditions with a percentage from 65.5 to 67.9 followed by July, and finally August (Table 3). Also, June had the high-est contribution in the general map (average of the three individual maps) followed by July and finally August. The area under the curve for the datasets of June, July, and August ranged from 0.57 to 0.74 based on the jackknife test (Table 4). The area under the curve for training data ranged from 0.93 to 0.94 and for test data

Table 3
Contribution percentages of monthly temperature datasets in the model maps for the near future.

Months	Maps			Average contribution ± S.D.
	Minimum temperature	Average temperature	Maximum temperature	
June	67.9	65.9	65.5	66.43 ± 1.28
July	22.6	31	21.9	25.16 ± 5.06
August	9.5	3.1	12.7	8.43 ± 4.88

Table 4
Values of area under the curve for monthly datasets from the jackknife test and for test/training data from the receiver operating characteristic curve of the model maps for the near future.

Datasets	Maps			Average value ± S.D.
	Minimum temperature	Average temperature	Maximum temperature	
June	0.74	0.72	0.66	0.70 ± 0.04
July	0.68	0.61	0.57	0.62 ± 0.05
August	0.64	0.58	0.61	0.61 ± 0.03
Training data	0.949	0.955	0.939	0.94 ± 0.01
Test data	0.750	0.727	0.677	0.71 ± 0.03
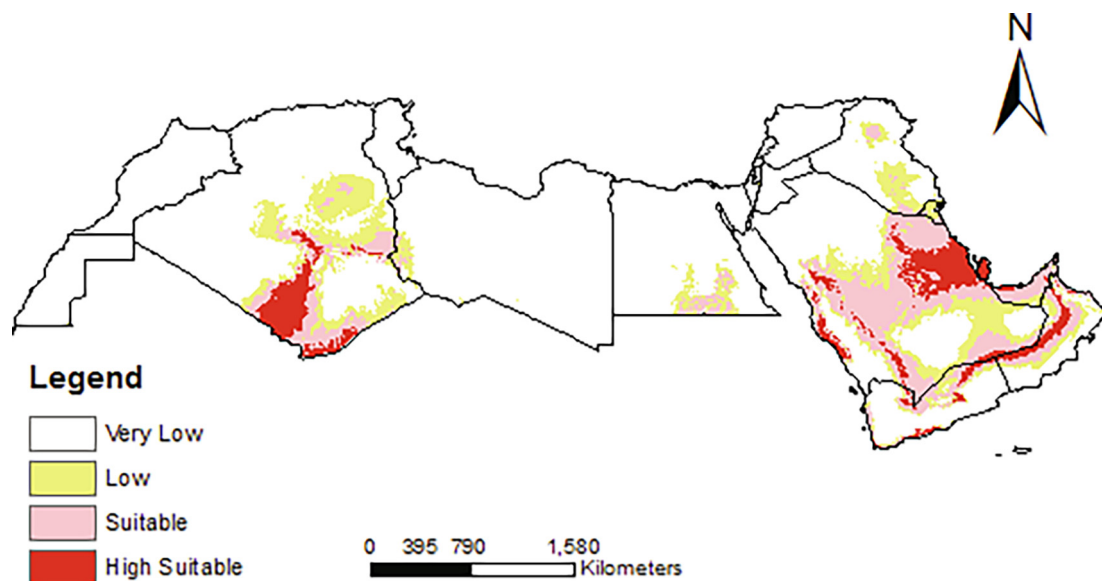
Fig. 5. Potential distribution of *Palarus latifrons* during near future conditions based on the average of three maps (minimum, average and maximum temperature) during summer (June, July and August).
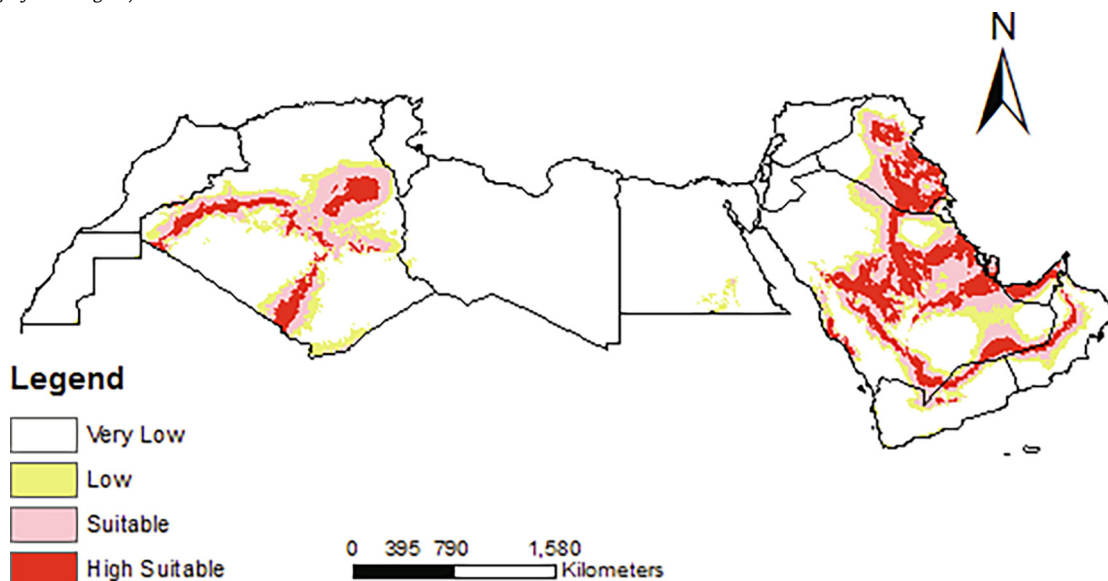
Fig. 6. Potential distribution of *Palarus latifrons* during conditions of near future based on two environmental variables (MTWM: Maximum temperature of the warmest month, and MTWQ: Mean temperature of the warmest quarter).

ranged from 0.67 to 0.75. The highest value was 0.94 ± 0.01 for the training data in the general map.

The model map during the near future based on summer conditions (Fig. 5) shows that the very high suitable areas for *Palarus latifrons* are concentrated in the western parts of Saudi Arabia, Yemen, Oman, and Emirates. Vast areas in the Gulf countries were classified as suitable for *Palarus latifrons.* In North Africa, some parts in south Egypt and Algeria were classified as suitable while the very high suitable areas were in southern Algeria. The coastal areas of the Arabian countries were classified as low suitable for this pest.

The model map based on two bioclimatic factors during the near future (Fig. 6) confirmed the high suitability of Gulf countries for *P. latifrons*. Also, vast areas in Algeria were classified as very high suitable for this pest. In Egypt, only some parts in the south were considered as very low suitable *P. latifrons*. The coastal regions in the Arabian countries showed very low suitability for this pest. This expectation is supported by all maps.

4. Discussion

The model performance to generate distribution maps based on summer conditions and the two bioclimatic factors was generally good according to the area under the curve especially for training/test data as the values were high. It is known that the highest values are an indication of the good performance of the used model (e.g. Mulieri and Patitucci, 2019; Hosni et al., 2020; Jamal et al., 2021).

The model maps clearly showed the high adaptation of *P. latifrons* to the harsh conditions of Gulf countries. It is expected that this pest can adapt to the conditions of several Arabian countries: Saudi Arabia, Yemen, Kuwait, Oman, Emirates, and Iraq. The occurrence of this pest in these countries is not well documented except in Saudi Arabia. The maps showed that *P. latifrons* do not prefer coastal regions. It is expected that bee pirates prefer warm and desert regions more than cold/temperate regions. Some parts in south Egypt, Libya, and Algeria are expected to be suitable for the prevalence of *P. latifrons* in case of its invasion of north Africa. The regions highlighted as suitable or very suitable in north Africa are typically desert areas with conditions similar to deserts in the Gulf countries. The variations between the model maps based on summer conditions and those based on the two bioclimatic factors were generally low. All maps confirmed the potential spread of *P. latifrons* in the Gulf countries. Also, all maps highlighted the presence of some suitable areas especially in Egypt and Algeria among the north African countries.

The situation during the near future based on the model maps is expected to be similar to the current situation. The effects of temperatures during the near future are expected to be low on *P. latifrons*. Gulf countries will be the main suitable regions for the spread of this pest. Some parts in Egypt, Libya, and vast areas in Algeria are expected to be suitable for *P. latifrons*. In fact, the direct movement of this pest to invade north Africa through Egypt is not expected because the northern parts of Africa were classified as very low suitable for this pest. The accidental introduction of this pest to North Africa is expected to happen during trading between the Arabian countries.

Beekeeping in the desert regions or close to desert regions are expected to suffer from the attack of bee pirates. In fact, deserts are used in beekeeping in some Arabian countries due to the presence of honey plants (Alghoson, 2004; Al-Ghamdi and Nuru, 2013; Abou-Shaara, 2015). Also, migratory beekeeping is considered the common type of beekeeping in Arabian countries (Al-Ghamdi and Nuru, 2013; Al-Ghamdi et al., 2016). Honey bees can tolerate desert conditions (Alqarni, 2006; Alqarni et al. 2011; Abou-

Shaara et al., 2013; Abou-Shaara, 2014; Abou-Shaara et al., 2017). So, apiaries can be established in the deserts for a short period during honey seasons. Such apiaries in the deserts or areas close to deserts are anticipated to be the main target of bee pirates. The options for the control of *P. latifrons* are limited and are not well documented unlike other bee pests (Arbogast et al., 2007; Beggs et al., 2008; Abou-Shaara, 2017; Rangel and Ward, 2018; Abou-Shaara and Staron, 2019).

5. Conclusion

The study aimed to investigate the possible spread of bee pirates *Palarus latifrons* in the Arabian deserts after their establishment in Saudi Arabia. Model maps using summer conditions and two bioclimatic conditions were established using Maxent and GIS. The model maps showed the high suitability of Gulf countries for this pest undercurrent and near-future conditions. The coastal regions showed very low suitability for this pest, suggesting its low ability to invade these regions. In North Africa, some parts in south Egypt and Libya were generally suitable for this pest. Vast areas in Algeria showed high suitability for this pest. No huge differences were observed between maps of current and near-future conditions. The direct movement of *P. latifrons* to invade Africa through Egypt is not expected during the near future. The accidental introduction through trading between the Arabian countries is expected to contribute greatly to the spread of this bee pest. Developing methods for the early detection of this digger wasp is required.

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.

Acknowledgement

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