

Article

Utilizing Ecological Modeling to Follow the Potential Spread of Honey Bee Pest (*Megaselia scalaris*) from Nearby Countries towards Saudi Arabia under Climate Change Conditions

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Abstract: The current challenge for the development of beekeeping is the possibility of bee pests invading new areas. It is well known that each geographical range has its unique pest species. The fly *Megaselia scalaris* is a facultative parasitoid to honey bees. This fly has been recorded in various countries while information about it in Saudi Arabia is still seldom. The main objective of this study was to follow the spread of this fly from North Africa/South Europe towards Gulf countries utilizing ecological modeling. Maxent, as a specialist software in analyzing species distribution, was used in combination of five environmental factors. The analysis was performed to cover current and future conditions (2050). The outputs of the model were analyzed in regard to their performance and distribution of *M. scalaris* in the study area. The top factor contributing to the model was the annual mean temperature with a percentage of 56.3. The model maps emphasized the possible occurrence of this pest in the northern parts of Saudi Arabia. The wide establishment and distribution towards the central and southern parts of Saudi Arabia were not supported. Screening apiaries located in Northern areas in Saudi Arabia for the presence of this pest using specific bait traps could be a good recommendation from this study.

Keywords: Gulf countries; modeling; GIS; Maxent; apiculture; honey bees



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1. Introduction

Saudi beekeeping has gained high attention from the agricultural sector [1]. Approximately, all Saudi Arabia is suitable for beekeeping, although the harsh conditions of some areas during summer [2] and various beehive types can be utilized for keeping bees [3]. Hybrid bees from different subspecies beside Yemeni honeybees are used in Saudi beekeeping [1,4,5]. These bee subspecies have been exposed to various studies to evaluate their purity and to enhance their characteristics [5–7]. Some of them are well adapted to the local conditions of Saudi Arabia and can tolerate harsh summer temperatures [8]. The exposure of honey bees to pests is among the top problems facing beekeeping improvement in the Arabian countries including Saudi Arabia [9]. A number of insect species has been recorded as pests for bee colonies such small hive beetles, Asian hornets, and parasitoid flies [10–17].

Some species of flies can perform parasitism on honeybees such as *Megaselia scalaris* (Diptera, Phoridae) [12,13]. The exposure of bees to the larvae of this fly can cause harmful damages to the body tissues of the bees which accelerates the death of the infected bees. In fact, *M. scalaris* has a wide range of hosts and can parasitize on animals [18–20], in addition to its ability to harm stored products [21]. This fly was recorded in some European and North African countries [22]. However, the pest status of *M. scalaris* to honey bees in some countries, including Saudi Arabia, is still not well known. Previous studies have highlighted the potential spread of bee pests to new regions in response to climatic change conditions [16,23]. Therefore, the potential spread of this fly from its current range in South Europe/North Africa towards Saudi Arabia is the main aim of this study.

The biological invasion of some new pests/species into new environments can be expected utilizing ecological modeling tools [24]. Such tools depend on using some mathematical approaches, such as the maximum entropy algorithm [16] available in MaxEnt [22,25,26], in addition to the use of geographical information system (GIS) which has useful applications in the beekeeping (apiculture) sector [27]. Consequently, ecological modeling was achieved during this study utilizing these computer programs. Some reports have shown the effects of temperature on beekeeping in the future [28,29]. Hence, environmental datasets based on temperature were exclusively used in some studies [16,22]. Therefore, the present modeling study aimed to track the potential expansion of *M. scalaris* recorded in South Europe/North Africa to invade new areas, especially Saudi Arabia, under current and near future conditions. Some practical recommendations were then suggested in light of the model maps.

2. Materials and Methods

2.1. Geographical Range and Records of *Megaselia scalaris*

The geographical range of this study was restricted to contain some countries in Europe, North Africa and the Arabian Gulf region. Records from three countries: two in Europe (Italy and France) and one in Africa (Algeria) were used in the modeling with a total of 60 records. The source of these records was Global Biological Information Facility [30] following the work of Abou-Shaara and Darwish [22].

2.2. Selection of Environmental Variables

Five environmental variables based mainly on temperature were downloaded from worldclim.org (WorldClim v2.1, 2020) according to previous publications [16,22,23]. Typically, these variables were the mean temperature of the warmest quarter, annual mean temperature, mean diurnal range, the maximum temperature of the warmest month, and minimum temperature of the coldest month with a spatial resolution of 5 km². The future datasets at a Shared Socio-economic Pathway of 245 (SSP245) from Beijing Climate Center (BCC-CSM2-MR) [31] were used to model the distribution of *M. scalaris* during future conditions (2050).

2.3. Modeling Steps and Evaluation

The environmental variables were handled firstly using ArcGIS 10.5 to change the datasets from TIF format into suitable format for Maxent analysis [24]. Then, the datasets were analyzed using software for ecological modeling (namely, Maxent v 3.4.1) [32] following user guide [33]. The model used 25% of the points in testing the model while the other points were used in training the model [22,24]. The outputs from the model yielded two maps, one for current conditions and the other one for future conditions (2050). The maps were subjected to analysis using ArcGIS to classify the study region into five classes [16].

The outputs of the model provided some key parameters for the evaluation of the used model [16,24,33]. These parameters include the contribution percentages of the used environmental variables in the model. This parameter allows the identification of the most important variables in the modeling. Moreover, the area under the curve for the used variables (test/training) is among the output which is a very important parameter for the evaluation of the model.

3. Results

3.1. Performance of the Model

The model depended on the contribution of 56.3, 30.7, 9.2, 2.3, and 1.5% of the annual mean temperature, minimum temperature of the coldest month, mean diurnal range, the maximum temperature of the warmest month, and mean temperature of the warmest quarter, respectively (Figure 1). Hence, the highest contribution was mainly from the annual mean temperature. The perfect range of each variable for *M. scalaris* was about 13–15 °C, 8–9 °C, 25–30 °C, and 2–4 °C for the annual mean temperature, mean diurnal

range, the maximum temperature of the warmest month, and minimum temperature of the coldest month.

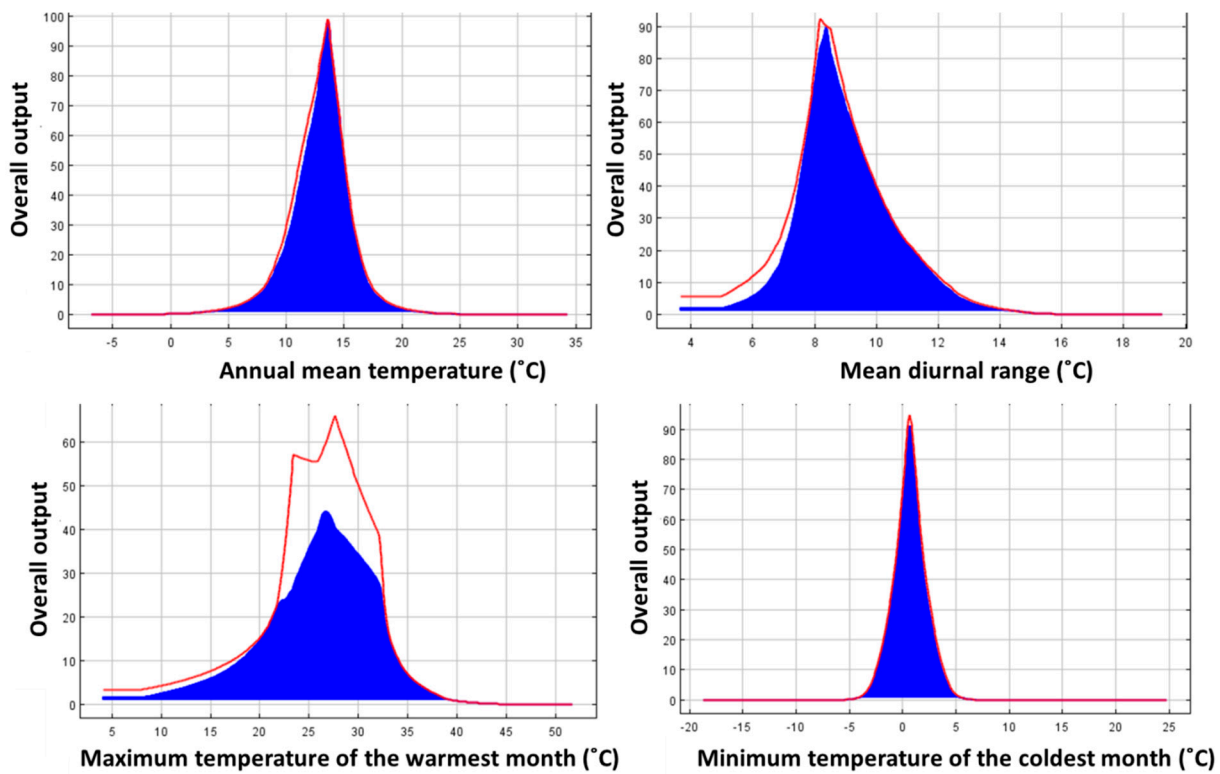


Figure 1. Response curves of the environmental variables with the highest contribution percentage in the model.

The mean omission was close to the predicted omission, as in Figure 2, especially at the fractional value of more than 0.7. Moreover, the mean area under the curve (Figure 3) was 0.949, suggesting that the used model had a high performance in light of the used variables and analysis options.

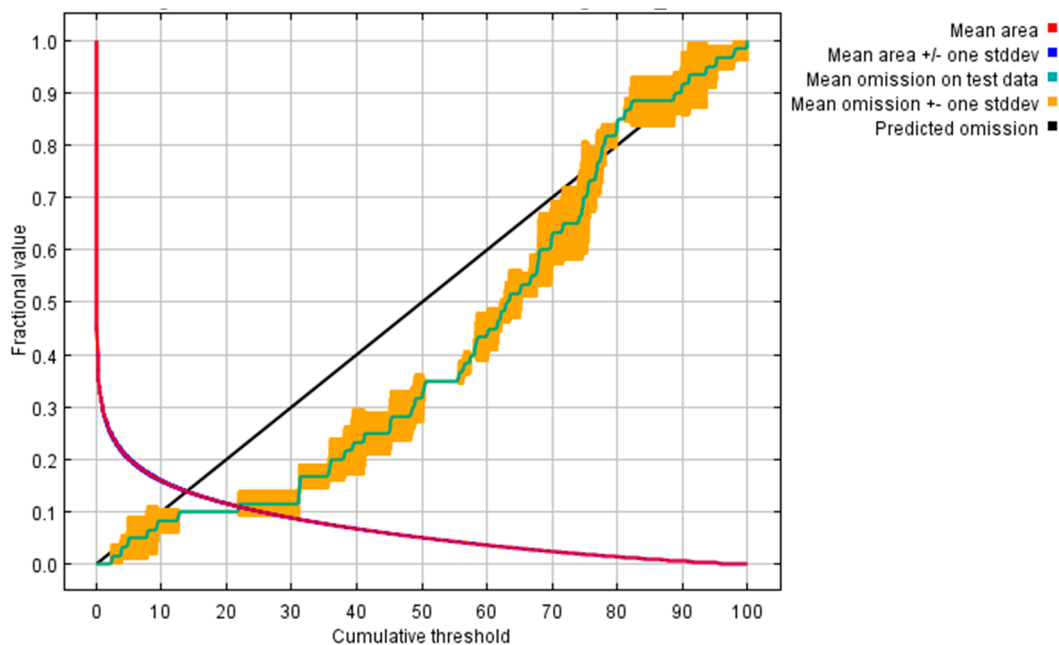


Figure 2. Analysis of omission and predicted area for *Megaselia scalaris*.

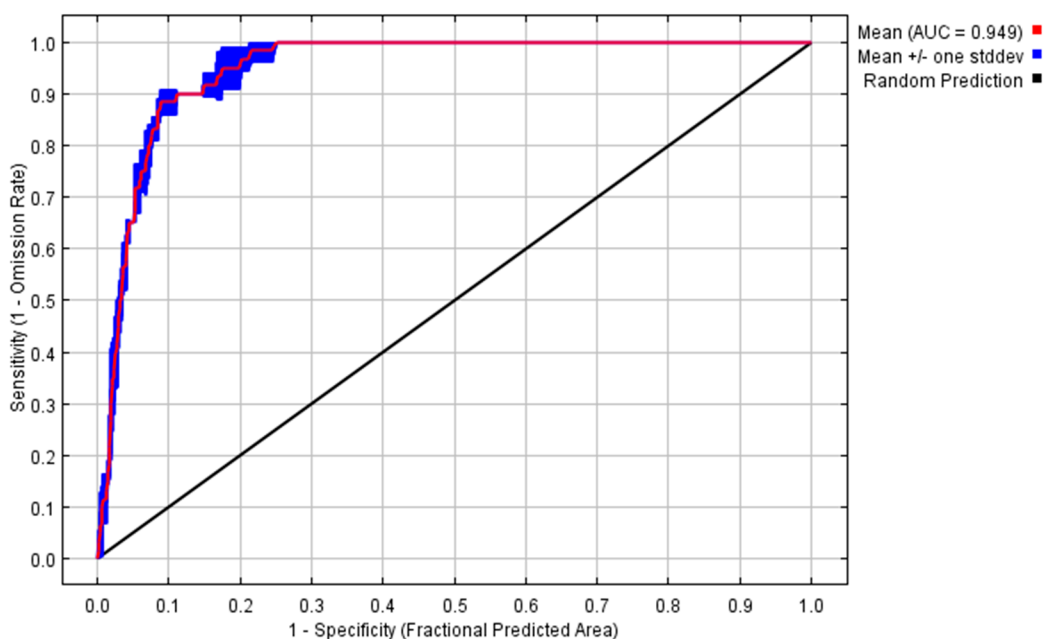


Figure 3. The receiver operating characteristic (sensitivity versus 1-specificity) for *Megaselia scalaris* mean of area under curve (AUC).

All temperature variables had a high area under the curve of more than 0.7 according to the jackknife test (Figure 4). The highest value was the annual mean temperature, followed by the minimum temperature of the coldest month, then the mean diurnal range, mean temperature of the warmest quarter, and finally maximum temperature of the warmest month.

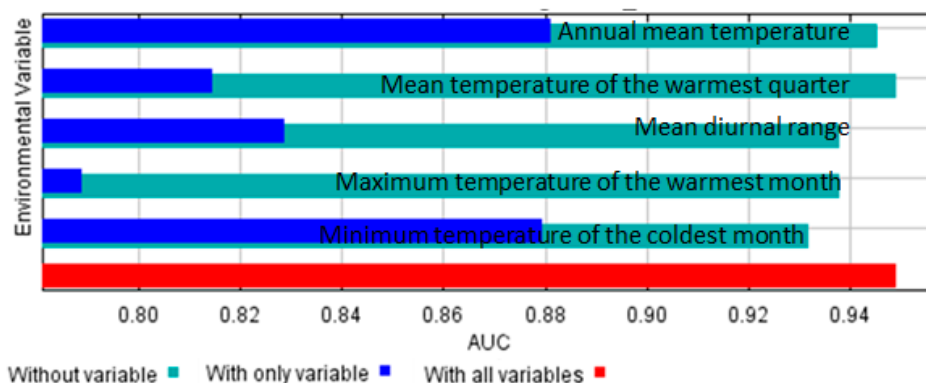


Figure 4. The area under curve (AUC) for the five temperature variables used in the model.

3.2. Model Map for Current Conditions

The model map (Figure 5) presents five classes for the spread of *M. scalaris* in the study area. The highly suitable and suitable areas for *M. scalaris* are restricted to some European countries such as Italy, Spain, and France as well as some parts of Tunisia, Algeria, and Morocco. The moderately suitable areas for *M. scalaris* were around areas highly suitable/suitable for this pest besides the Levant. The occurrence of *M. scalaris* was considered as possible in the northern parts of Saudi Arabia beside other parts in north Africa/Europe. The vast area of Saudi Arabia was classified as seldom for the spread of this pest.

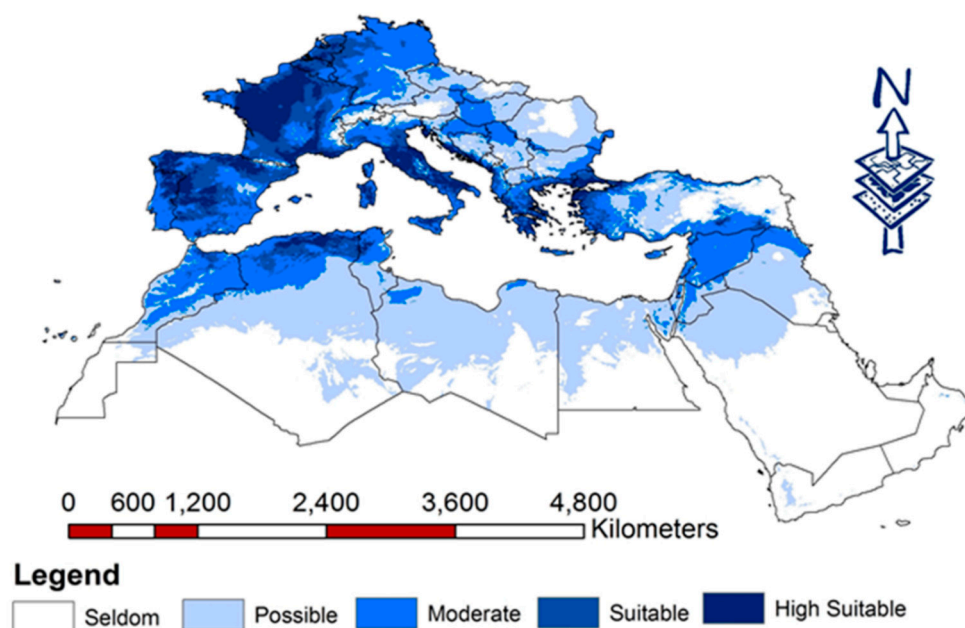


Figure 5. Model map for current conditions showing the distribution of *Megaselia scalaris* in the study area.

3.3. Model Map for Future Conditions

The model map (Figure 6) for future conditions during 2050 tracked the spread of *M. scalaris* in the study area. Similarly to the previous map, European countries from Turkey in the east to Portugal in the west were considered as high to moderate suitable for this pest. In north Africa, climatic conditions are expected to negatively affect the spread of this pest turning the majority of the area as seldom suitable for the spread of *M. scalaris*. Some northern parts in Algeria and Morocco are mainly expected to be suitable for this fly. In a way similar to the previous map, the northern parts of Saudi Arabia are expected to be possible locations for the spread of *M. scalaris* unlike the rest of the kingdom. Mostly, the spread of *M. scalaris* in Saudi Arabia is not expected to be highly affected by future environmental conditions, unlike the situation in north Africa.

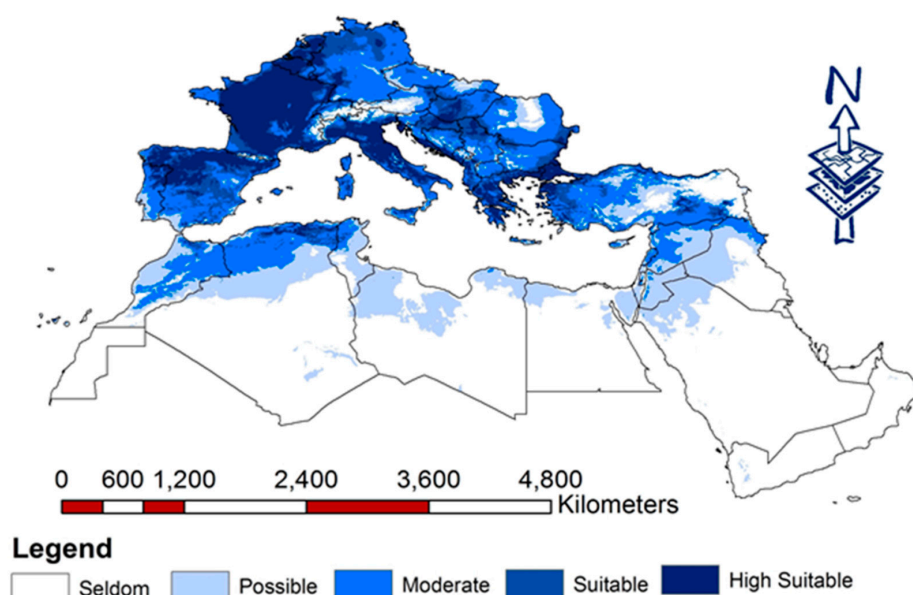


Figure 6. Model map for future conditions (2050) showing the distribution of *Megaselia scalaris* in the study area.

4. Discussion

The use of Maxent modeling for studying harmful and beneficial insects either for control or conservation has increased during the last decade [24,34–36]. This study focused on one of the neglected honey bee pests using this technique to evaluate its risk of attacking apiculture in Saudi Arabia. The suitable temperature of the used variables in the model was moderate to high. Similarly, a recent study found that high temperature (i.e., warm weather) is better for the prevalence of *M. scalaris* [22]. Moreover, the present study showed the high contribution of the annual mean temperature in the model. In fact, temperature is a limiting factor for *M. scalaris* development [37–39], with the highest prevalence in the summer period [40]. The mean omission was close to the predicted omission which suggests the very good performance of the ecological model [23]. In addition to this point, the mean area under the curve was 0.949 and less than one by 0.051; additionally, all temperature variables had a high area under the curve more than 0.7. Such high values denote the perfect performance of the model according to previous ecological modeling studies [16,22,24,41].

The model map for the present conditions highlighted the high spread of this bee pest in western parts of Africa and European countries. The results of this map are close to the real situation of this pest in the study area based on the occurrence records in Algeria, France, and Italy. Accordingly, similar areas were previously classified as suitable for *M. scalaris* [13,22,40,42]. The northern parts of Saudi Arabia were considered as a possible destination for the occurrence of *M. scalaris*. Therefore, these regions are mostly the entrance gates of *M. scalaris* from Europe/Africa to Saudi Arabia. In fact, the weather of these areas is suitable for beekeeping in Saudi Arabia [2]. Thus, bee colonies could host this pest when these northern regions are invaded. Fortunately, the other parts of Saudi Arabia were not classified as suitable for this pest based on the used model. Therefore, beekeeping in such parts is not anticipated to be influenced by *M. scalaris* in a destructive way. The map also emphasized that northern parts of Africa could be good locations for the occurrence of *M. scalaris*. Perhaps this relates to the moderate weather in such regions due to the proximity to the Mediterranean Sea. This expectation is supported by previous findings related to the prevalence of *M. scalaris* in coastal regions [22,40].

The model map for future conditions did not show greater variations than the map of the present conditions. This suggests the absence of high effects of climatic conditions on *M. scalaris* in the study area. This finding is highly supported by a previous study as no great variations in the prevalence of this pest due to climatic conditions were detected [22]. The map confirmed that the northern parts of Saudi Arabia are possible areas for the occurrence of *M. scalaris*, without great spread towards central and southern parts. Perhaps the weather conditions, especially temperatures in the northern parts, are more suitable for *M. scalaris* than the rest of Saudi Arabia. In fact, this particular pest has not been monitored in Saudi apiaries, unlike other pests which have gained more attention [9]. Moreover, a number of parasitic flies can attack bee colonies [15,43,44]. Thus, the use of specific monitoring tools such as traps [45] should be developed to evaluate the infestation level with parasitic flies in Saudi Arabia during future research programs. On the other hand, some Diptera species, including some medical pests, show a high degree of range modification due to climate changes [46], so more studies are needed to evaluate the effect of global warming on agriculture and medical flies in different parts of the world.

5. Conclusions

The study was performed to track the possible invasion of *Megaselia scalaris* (a pest to honey bees) from Europe/Africa to Saudi Arabia. Ecological modeling using Maxent, GIS, and five variables related to temperature datasets was accomplished to realize this objective under current and future climate conditions. Among the used variables, annual mean temperature occupied the first rank in the contribution to the model with a percentage of 56.3. The model for *M. scalaris* showed perfect performance in light of the used analysis options and parameters. The obtained maps showed that the northern parts of Saudi Arabia are the contact zones through which the invasion of *M. scalaris* could happen but

without spreading widely towards the central and southern parts of the kingdom. Climatic conditions in the future (2050) are not anticipated to cause great changes in the distribution of *M. scalaris* based on the used model. It is recommended to screen apiaries, especially those located in northern areas in Saudi Arabia, for the presence of this pest using specific bait traps. Moreover, future research directions should consider studies on this pest in beekeeping areas.

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