Saudi Journal of Biological Sciences 28 (2021) 2049–2055

Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

Original article

Spatio-temporal analysis of Egyptian flower mantis *Blepharopsis mendica* (order: mantodea), with notes of its future status under climate change

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ARTICLE INFO

Article history:
Received 10 December 2020
Revised 10 January 2021
Accepted 12 January 2021
Available online 20 January 2021

Keywords:
Habitat suitability modeling
Mantis
Geo-information
Biodiversity informatics
Egypt

ABSTRACT

Egyptian flower mantis *Blepharopsis mendica* (Order: Mantodea) is a widespread mantis species throughout the southwest Palearctic region. The ecological and geographical distribution of such interesting species is rarely known. So, through this work, habitat suitability models for its distribution through Egyptian territory were created using MaxEnt software from 90 occurrence records. One topographic (altitude) and eleven bioclimatic variables influencing the species distribution were selected to generate the models. The predicted distribution in Egypt was focused on the Delta, South Sinai, the north-eastern part of the country, and some areas in the west including Siwa Oasis. Temporal analysis between the two periods (1900–1961) and (1961–2017) show current reduction of this species distribution through Delta and its surrounding areas, may be due to urbanization. On the other hand, it increases in newly protected areas of South Sinai. Under the future climate change scenario, the MaxEnt model predicted the habitat gains for *B. mendica* in RCP 2.6 for 2070 and loss of habitat in RCP 8.5 for the same year. Our results can be used as a basis for conserving this species not only in Egypt, but also throughout the whole of its range, also, it show how the using of geo-information could help in studying animal ecology.

1. Introduction

Mantodea is a small insect order which includes more than 2400 valid species under 446 genera that are classified through 14 families (Otte and Spearman, 2005; Roy, 2014). With 60 recorded species, Egypt is home to the largest number of Mantodea species through the Palearctic region (Mohammad et al., 2011). Comparing Egypt's Mantodea fauna to that of surrounding countries such as Saudi Arabia and Iran (Ghahari and Nasser, 2014; Kaltenbach, 1982; 1991), the geographical position of Egypt and its history in the center of the Old World coupled with the nature of the life cycle of insect itself could form the main reasons for such great diversity (Enan et al., 2017). One of most interesting species of such great fauna is Egyptian flower mantis. The Egyptian flower mantis *Blepharopsis mendica* (Fabricius, 1775) (Empusidae) has a unique and characteristic appearance that camouflages it against Mediterranean floral background (Battiston et al., 2010).

Globally, *B. mendica* is distributed through North Africa and the Middle East, from the Canary Islands to India (Ehrmann, 2002). Scanty information is known about its local distribution and habitat requirements. Only some basic information about preferred temperature and relative humidity is available (Bischoff et al., 2001; Heßler et al., 2008). According to the IUCN Red List, globally *B. mendica* is assessed as Least Concern due to lack of information (Battiston et al., 2010). Battiston through its assessment for IUCN stated that species distributed as small local subpopulations with fragmented pattern which need more investigation to reassess its conservations status (Battiston, 2016).

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.sjbs.2021.01.027
1319-562X/

Understanding the habitat of *B. mendica* requires awareness of the combination of factors that species inhabits, and of course the geographical required habitat has a significant impact on the distribution (Yi et al., 2016). Biodiversity informatics and geographical information systems (GIS) are new tools that help in studying biological unties using several modeling techniques (Canhos et al., 2004; Proença et al., 2017). Habitat suitability modelling can make predictions of the distribution as a function of climate and topography (Elith et al., 2011). Such methodology use presence/absence or present only data along with spatial environmental variables ('Geographical information layers') to estimate the niche and project this onto the landscape. The results will make revolutionary impact on biodiversity conservation which face many problems today (Guisan and Thuiller, 2005; Leach et al., 2013; Nasser et al., 2019).

Insect communities faces the same problems that threaten all earth biodiversity: habitat destruction and fragmentation, climate change, and insufficient available data (Romoser, 1981). Combinations of these factors are the main reason for the endangerment and loss of insect species globally (Tilman et al., 2001). *B. mendica* faces many of these challenges through different parts of its range including its habitats in Egypt. Its occurrence records have decreased through the last few decades. This is can appear clearly through revision of its specimens collected in the main Egyptian insect reference collections (Mohammad et al., 2011).

The aim of this work is to use occurrence records of *B. mendica* to model its habitat suitability through Egyptian territory to provide a better understanding of its ecology and consequently its conservation using combination of geo-information and biodiversity data. This is through prediction of its habitat suitability in two historical periods (1900–1960, 1961–2017) and estimate its future distribution under two climate warming scenarios (RCP2.6 and RCP8.5, given by the IPCC for 2070).

2. Materials and methods

The study was conducted in Egypt, located in the northeastern corner of Africa, and covering approximately 1,001,449 km^2 (https://www.cia.gov). Egypt is divided into eight ecological regions: Coastal Strip, Lower Nile Valley (including the Delta), Upper Nile Valley, Fayoum Basin, Eastern Desert, Western Desert, Sinai and Gebel Elba (El-Hawagry and Gilbert, 2014; Okely, M. et al., 2020b). This is reflected on the floral and faunal composition of the country. It has warm and almost rainless climate, but the Coastal strip, Eastern Desert, Gebel Elba and higher parts of the southern Sinai Mountains receive higher rainfall (El-Hawagry, 2002).

Ninety occurrence records of *B. mendica* were collected from biodiversity databases, including Project Noah http://www.projectnoah.org, the Global Biodiversity Information Facility (GBIF), museum collections include the State Museum of Natural History Karlsruhe (SMNK) (Germany); Ain Shams University collection (ASUC), Cairo University Collection (CUC), Egyptian Society of Entomology collection (EESC), Al-Azhar University Collection (AUC) (Egypt), and from the literatures (Ehrmann, 1996; El-Moursy et al., 2001; Mohammad et al., 2011) (Supplementary **1&2**). This beside field collections which take place through ten sites (Sharm El Sheikh, Ras Sedr (South Sinai), Hotel Novotel (Marsa Alam), Port Said, Qeft road and Bharr (Elqoseir)), Fatirah (Aswan), Wadi Qena, Nagaa Ad Dibabiyyah (Luxor), Alazhar Park (Cairo) to validate our model. Sweeping net was used to collect this insect from the field, also searching vegetation visually. Identification was carried out with the aid of (Mohammad et al., 2011).

The climatic data for the period of 1900 to 2010 were downloaded from the WorldClim database (http://www.worldclim.org/) with spatial resolution 2.5 min and clipped to match the dimensions of Egypt using ArcGIS 10.3. The data were extracted for the species by using the "extract by mask" function in Arc Map to focus the results on the South Sinai protected areas. Climatic data projected to the year 2070 from the global climate model of the Meteorological Research Institute (MRI-CGCM3), RCP2.6 and RCP8.5 were used to assess the effects of climate change. These data are among the recent GCM climate projections that are used in the fifth Assessment IPCC Report (Hosni et al., 2020).

MaxEnt version 3.3.3k was used to model the present and future potential distribution of *B. mendica* (Elith et al., 2011). The program estimates the habitat suitability for each cell on the map, varying from 0 (lowest suitability) to 1 (highest suitability), and provides the contribution of each bioclimatic variable to the prediction. The occurrence records were randomly partitioned for model evaluation into two subsamples: 75% of the records were used for training and 25% of the records were used for testing. To improve model accuracy, 10-fold cross-validation was used to create 10 replicates, generating a maximum, minimum and median distribution range (Khanum et al., 2013). In this study, a combination of 19 climatic and 3 topographical variables was initially used to predict current and future distribution of *B. mendica*. We remove bioclimatic variables 8–9 and 18–19 from analysis, due to spatial artifacts in those four variables (Okely et al., 2020a) and then select the variables that have more contribution to the Model. Finally, a set composed of 12 variables were selected (Table 1). The area under curve (AUC) were used for model evaluation. The value of AUC lies between 0.5 and 1, with thresholds of 0.5 (no better than random), 0.5–0.7 (low), 0.7–0.9 (useful) and >0.9 (excellent) (Swets, 1988).

The realized niche of *B. mendica* can be evaluated by using the occurrence points and climate data. The histogram tool of DIVA-GIS 5.4 software (http://www.diva-gis.org/) was used to calculate the frequencies of the different climate parameter ranges (Hijmans et al., 2001), and to evaluate the two-dimensional climate niche based on two climate parameters to identify the potential climate ranges to which the species is adapted (van Zonneveld et al., 2009). All the generated models depended only on the bioclimatic factors and did not take into consideration the effects of urbanization or other human impacts.

3. Results

The climatic niche of *B. mendica* was estimated for each of the bioclimatic factors (Table S2, **Supplementary 3&4**): a suitable climate envelope is the temperature range 20.8–23.4 °C coupled with low precipitation 0–36.8 mm (Fig. 1).

The current predicted distribution of the species through Egypt showed areas with high suitability in the Delta, South Sinai, the northeastern part of the country (Ismailia, Port Said and Suez) and the Red Sea coast. There were also some areas predicted to be suitable in the west, including Siwa Oasis (Fig. 2a). The Maxent model was excellent with an AUC of 0.95. Temperature related variables had contribution of 45.3% to the model. Among these variables, Temperature Annual Range (bio7) gave the highest influence on the model with 30.2% (Table 2). Altitude showed higher effect on the distribution of the species relative to other variables with contribution of 34.8% to the model. Not only the probability of maximum presence of *B. mendica* increased with increasing altitude but also the species preferred the low altitude at 0 levels (**Supplementary 5**). Precipitation related variables had relatively small influence on the model with only 20% contribution. Among these variables Precipitation of Wettest Quarter (bio 16) gave the highest influence on the model with 13.3% contribution.

Table 1
Environmental variables used for modeling the habitat suitability distribution of *B. mendica* in this study.

Units	Abbr.	Variables	Category	Data Source
m	**Alt.**	Altitude	Topographic	Geospatial Data Cloud
				WorldClim
		Mean Diurnal Range (max temp – min temp)	Bioclimatic	
C°	**Bio2**			
		Temperature Seasonality (standard deviation *100)		
C°	**Bio4**	Max Temperature of Warmest Month		
C°	**Bio5**	Min Temperature of Coldest Month		
C°	**Bio6**	Temperature Annual Range		
C°	**Bio7**	Mean Temperature of Warmest Quarter		
		Mean Temperature of Coldest Quarter		
	Bio10			
C°		Annual Precipitation		
C°	**Bio11**	Precipitation of Wettest Month		
		Precipitation Seasonality (Coefficient of Variation)		
mm	**Bio12**			
		Precipitation of Wettest Quarter		
mm	**Bio13**			
Dime.less	**Bio15**			
mm	**Bio16**			

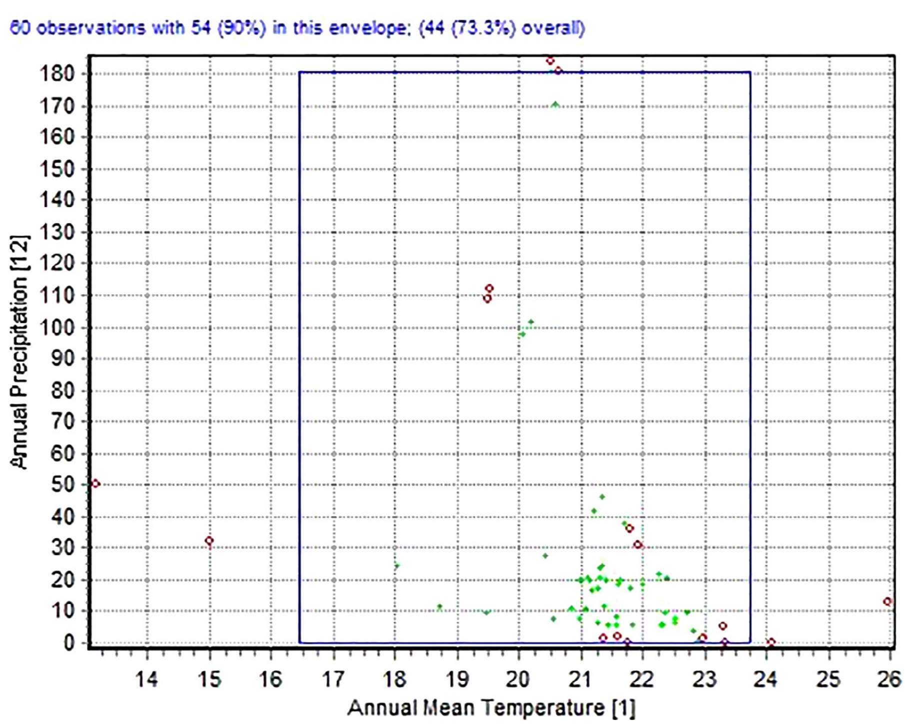

Fig. 1. Diagrammatic representation of a two-dimensional bioclimatic envelope (Annual Mean Temperature and Annual Precipitation).

Habitat suitability for the two historical periods (1900–1960:1 961–2017) (Fig. 3) showed that suitability in the earlier period (Fig. 3a) was focused on Cairo and the Lower Nile Valley, and the area around Suez, together with the upper Red Sea coast, whilst in the later period (Fig. 3b) the hotspots had shifted to South Sinai and retaining the upper Red Sea coast. Four Protected areas and national parks (St. Catherine Protectorate, Nabq Protected area, Ras Mohamed National Park and Abu Galum Protected Area) in

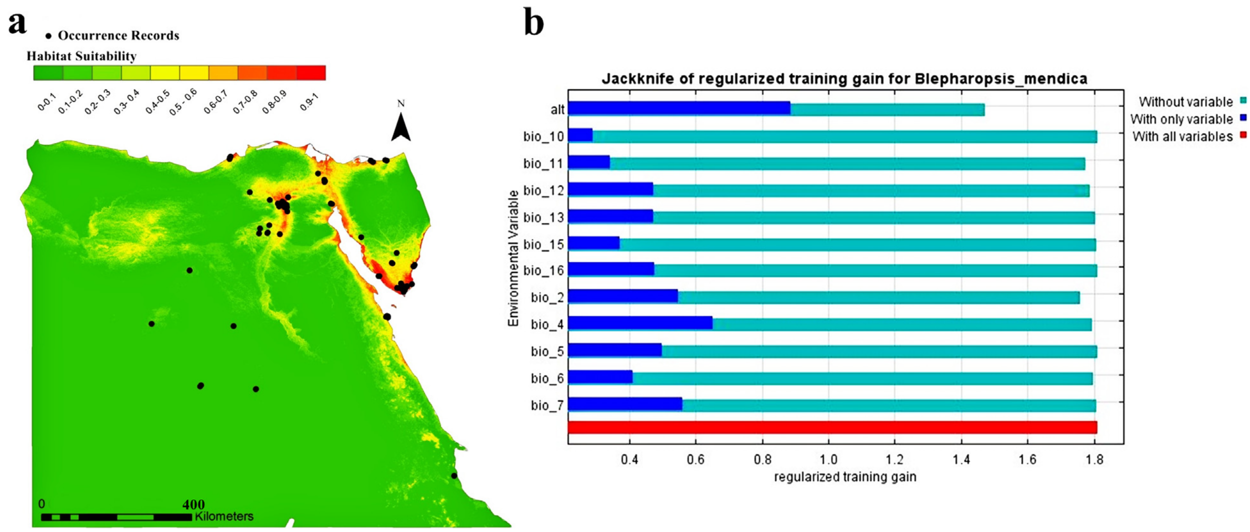

Fig. 2. a. Habitat suitability of *B. mendica* according to occurrence records; **b.** Relative importance of environmental variables based on jacknife of regularized training gain in MaxEnt model for *B. mendica*, Values shown are average over 10 replicate runs.

Table 2
The percentage of contribution of each environmental factor affect the predicating spatial distribution of *B. mendica.*

Contribution %	Description	Variable
34.8	Altitude in degrees	Altitude
	Mean diurnal range (max temp – min temp)	bio_2
5.3		
	Temperature seasonality (standard deviation *100)	bio_4
1.9		
	Max Temperature of Warmest Month	
1.6		bio_5
	Min Temperature of Coldest Month	
0.8		bio_6
	Temperature Annual Range	
30.2		bio_7
	Mean Temperature of Warmest Quarter	
0.2		bio_10
	Mean Temperature of Coldest Quarter	
5.3	Annual Precipitation	bio_11
4	Precipitation of Wettest Month	bio_12
13.3	Precipitation Seasonality (Coefficient of Variation)	bio_13
0.2		
2.5	Precipitation of Wettest Quarter	bio_15
		bio_16

South Sinai showed very high habitat suitability in this period (Fig. 4).

To validate the models in the field, six sites where *B. mendica* was predicted to be present (suitability > 0.7), and four sites where it was predicted to be absent (suitability < 0.4) were selected randomly. Several visits were done to these areas to evaluate our model. We found *B. mendica* in all six sites where it was predicted to be present (Sharm El Sheikh, Ras Sedr (South Sinai), Hotel Novotel (Marsa Alam), Port Said, Qeft road and Bharr (Elqoseir)) and on the other hand it was absent in all four sites where it was predicted to be absent (Fatirah (Aswan), Wadi Qena, Nagaa Ad Dibabiyyah (Luxor), Alazhar Park (Cairo)) (Table 3).

The fifth IPCC report described four future climate-warming scenarios. RCP2.6 and RCP8.5 were two of these scenarios. The results of *B. mendica* habitat suitability in RCP2.6 for 2070 showed that habitat suitability increased with climate warming, and the warmer the climate is, the higher the habitat suitability is, while the case of RCP8.5 for 2070 the habitat suitability decreased with climate warming (Fig. 5). This mean that the species prefer warm climate till certain point by which the habitat suitability dramatically decreased.

4. Discussion

In recent years predicting species distributions has become important for conservation planning, and a wide variety of modeling techniques have been developed for this purpose (Guisan and Thuiller, 2005; Okely, M. et al., 2020b). According to IUCN Red List of Threatened Species, *B. mendica* needs further monitoring to understand potential threats and confirm its conservation status throughout its natural range (Battiston et al., 2010). Throughout this work, distribution maps and produced habitat suitability models were established for *B. mendica* in Egypt, using GIS and MaxEnt modeling.

Model evaluation were classified as "excellent" with high AUC values (Shao et al., 2009), this is beside fieldwork validation to some of the predicted range which give 100% accuracy (Table 3). In the real world, the species may not actually occupy all sites deemed suitable by the model because the modelling does not consider other factors influencing the distribution, such as dispersal processes, biotic interactions, urbanization, and geographic barriers.

By using same climatological and topographical variables with two different sets of species recorded points, the result will give us an idea about the change that occurs to species distribution through the two different period of collections (Yi et al., 2016). Splitting *B. mendica* occurrences in Egypt into two different historical periods revealed that the suitable habitat in the period 1900–1960 was focused on the Delta, while for 1961–2017 the habitat was deemed more suitable on the Red Sea coast and in South Sinai. Records of *B. mendica* have become scarce in the Delta and around Cairo in the last few decades, perhaps due to increasing human

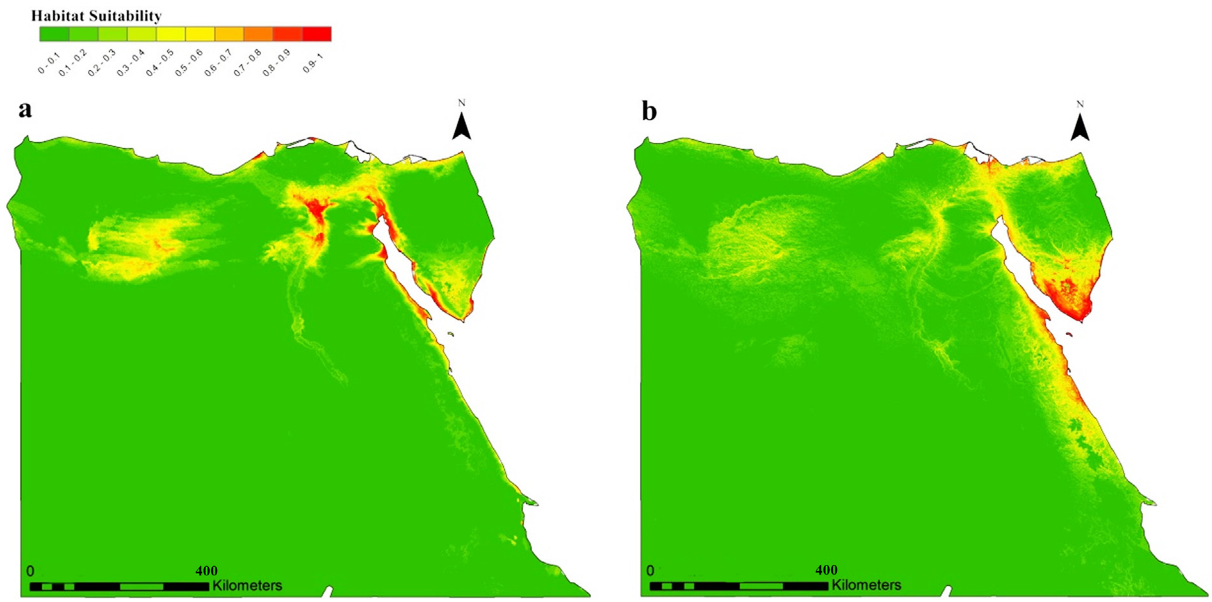

Fig. 3. Habitat suitability of *B. mendica* in two historical periods. a 1900–1960b 1961–2017.

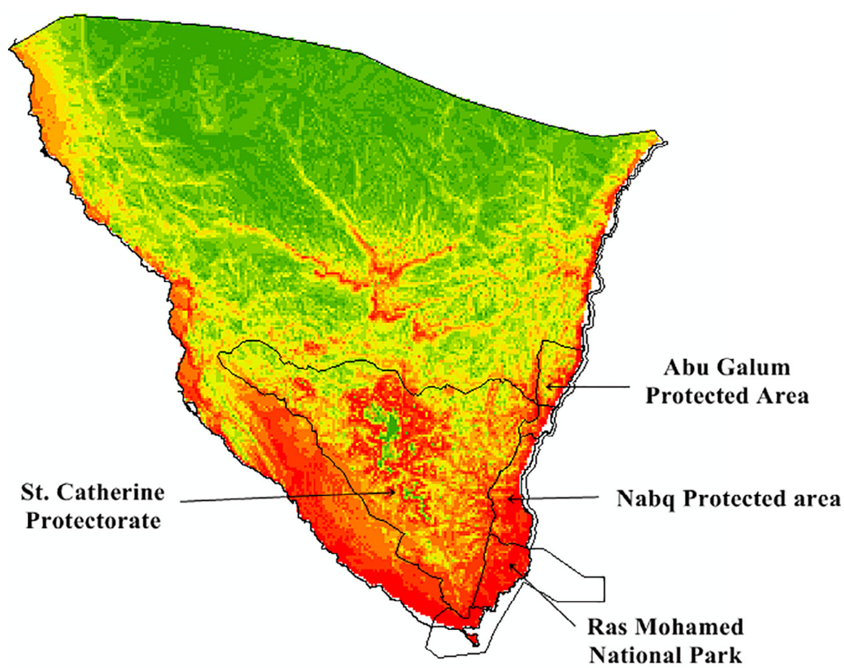

Fig. 4. Habitat suitability of *B. mendica* in South Sinai protected areas in the period (1961–2017).

Table 3
Field validation for the habitat suitability of *B. mendica* through the different eight ecological regions of Egypt.

Place	Date	Latitudes	Longitudes	Present or absent
Fatirah (Aswan)	15-Aug-2016	24.61222222	32.92861111	Absent
Wadi Qena	10-Feb-2017	26.34777778	32.87138889	Absent
Nagaa Ad Dibabiyyah (Luxor)	20-Aug-2016	25.49361111	32.51388889	Absent
Alazhar Park (Cairo)	15-Mar-2017	30.04083333	31.265	Absent
Sharm El Sheikh (South Sinai)	18-Apr-2017	27.97027778	34.14166667	Present
Ras Sedr (South Sinai)	18-Apr-2016	29.58972222	32.70611111	Present
Hotel Novotel (Marsa Alam)	01-Sept-2016	26.27277778	34.15638889	Present
Port Said	28-Mar-2015	31.07305556	32.30277778	Present
Qeft road (Elqoseir)	20-Aug-2017	26.10774036	34.20476067	Present
Bharr (Elqoseir)	19-Aug-2017	26.0220730	34.3244640	Present

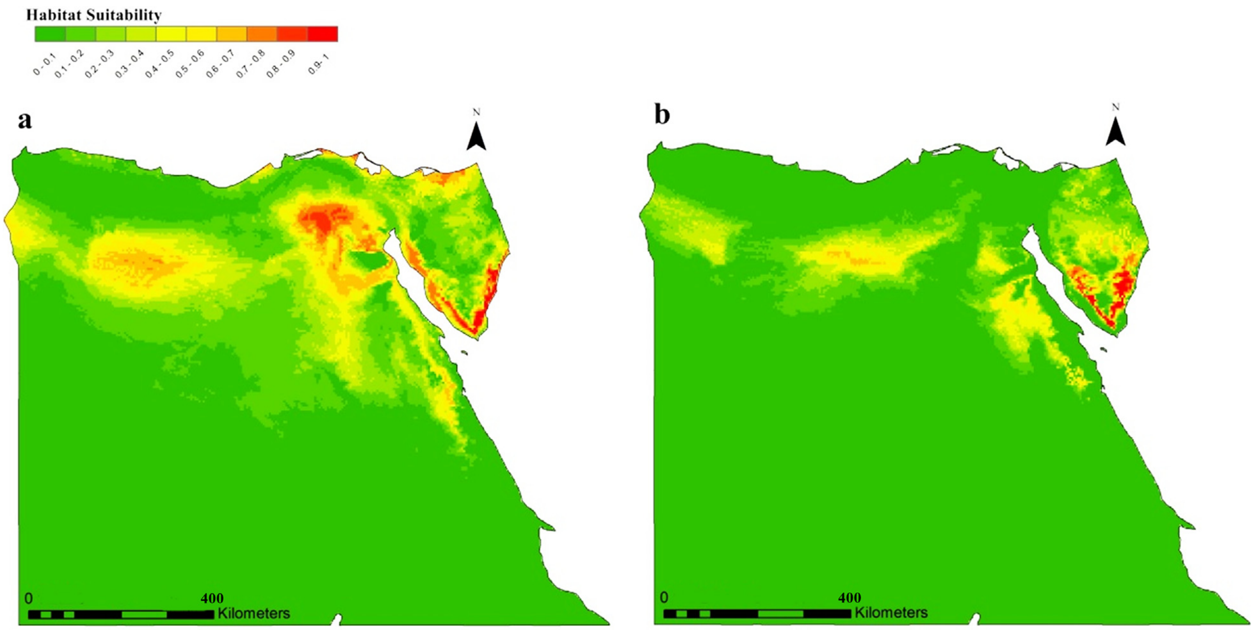

Fig. 5. a. Predicted future distribution of habitat suitability of *B. mendica* under RCP 2.6 emission scenarios for 2070; **b.** Predicted future distribution of habitat suitability of *B. mendica* under RCP 8.5 emission scenarios for 2070.

population density, human activities and urban infrastructure. Satellite images for Cairo and its surroundings show such effects clearly through recent years (**Supplementary 6**). Simultaneously habitat suitability was predicted to increase through the Red Sea coast and South Sinai. The declaration of several protected areas and national parks (St. Katherine Protectorate, Nabq Protected area, Ras Mohamed National Park and Abu Galum Protected Area) in this region perhaps has encouraged insect communities including *B. mendica*. This could explain why the species record and generated models indicating such increase in habitat suitability for the species on this region.

The potential habitats of *B. mendica* under two climate warming scenarios were predicted. RCP2.6 for 2070 showed *B. mendica* habitat suitability increasing with climate change. However, RCP8.5 for 2070 showed large losses of suitable habitat in Egyptian mainland, and populations appear to shift to high altitudes in South Sinai in response to climate change. Climate change can impact the pattern of biodiversity through changes in distribution (Thuiller et al., 2005), and terrestrial organisms either shift latitude or elevation range in response (Chen et al., 2011).

Temperature-related variables collectively had the highest contribution to the model, while precipitation-related variables had relatively small influence. Among the temperature related variables Temperature Annual Range gave the highest influence to the model with 30.2%. The preferred temperature for this species is between 30 and 40 °C, with night-time temperatures not less than 23 °C (Bischoff et al., 2001; Heßler et al., 2008), which slightly differ from our results in this study. Finally, our results form a beginning step on a better understanding of current and future distribution for this interesting species through Egypt.

5. Conclusions

The present work represents the first use of habitat suitability modeling in studying mantis ecology. Although the result for *B. mendica* did not suggest any great threat to this species in Egypt, especially in the Protected Areas of South Sinai, we know that urbanization and habitat destruction could decrease populations even with favorable climate and suitable circumstances. This appears clearly with the model produced for the period 1961–2017. There is a long way to go to understand the *B. mendica* niche throughout its huge range from the Atlantic Ocean to the Indian subcontinent, and more efforts are needed in this direction. The use of habitat suitability modeling and geo-information techniques represents a very promising tools for studying Mantodea, especially for endangered and critically endangered species such as *Pseudoyersinia canariensis* and *Ameles fasciipennis*.

Acknowledgments

This work is funded by Researchers Supporting Project, King Saud University number (RSP-2020/257), Riyadh, Saudi Arabia, so all authors appreciate king Saud University help. The work is a part of the M.Sc. of the second author, which concerns the distribution and habitat suitability of *B.mendica* in Egypt. The authors are grateful to Reinhard Ehrmann of the Staatliches Museum für Naturkunde Karlsruhe, and Roberto Battiston of the Musei Civici di Valstagna, for all of their support, and also for by providing us with very important literature. We are grateful to Francis Gilbert, Nottingham University, for his revision of linguistic mistakes. We also thank Abdallah Samy of the Department of Ecology, Evolutionary Biology & Biodiversity Institute, University of Kansas, for his support and providing us with the future climate warming scenarios; Eslam Mohamed Hosni of the Department of Entomology, Faculty of Science, Ain Shams University; and Watter Elbahry of Wildlife Masry for their help in the field validation.

Funding

This research was funded by Researchers Supporting Project, King Saud University number (RSP-2020/257), Riyadh, SaudiArabia.

Conflicts of interest

Authors have no conflict of interest.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sjbs.2021.01.027.

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