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Mantodea oasis of Palaearctic region: biogeographical analysis of Mantodea in Egypt

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Abstract

Background: Egypt forms a home for the highest number of recorded Mantodea species of the Palaearctic Region. The status and ecology of such diversity are far from being completely understood.

Main body: Through this study, the similarity of Mantodea species composition among Egyptian ecological zones has been examined by using the Sørensen-Dice coefficient, beside the calculation of species richness for each zone. Also, maximum entropy (Maxent) modeling was used to estimate the potential distribution of Mantodea species throughout the country. Three topographical and 19 bioclimatic variables have been used to estimate the current status of all Mantodea species in Egypt. The collected materials of adult mantis have been used to analyze the seasonality of 14 Egyptian common genera. Our results indicated that there was a high faunal similarity between the Western and Eastern deserts, the coastal strip, and the lower Nile valley. The lowest similarity was between Gebel Elba and all other zones. The analysis of habitat suitability of Mantodea in Egypt was fragmentary and focused on different distinct ecological zones. Altitude was the most effective ecological factor that affected Mantodea distribution as a group. Analysis of seasonality data of the common genera of Mantodea indicated that all are found in summer except for *Miomantis*, *Severinia*, and *Sinaiella*.

Conclusion: Our results can be used as a basis for future studies of the ecology of certain species and conservation of this interesting group in Egypt.

Keywords: Maxent, Climatic niches, Sørensen-Dice coefficient, Ecological zones, Egypt

Background

Mantodea is a group of mostly large predatory insects, distributed in tropical and subtropical habitats of the world (Ehrmann 2001; Otte and Spearman 2005). It includes approximately 2500 species (Ehrmann 2002; Schwarz and Roy 2019; Greyvenstein et al. 2020). Mantis is exclusively carnivorous feeding mainly on other arthropods as well as small vertebrates (Prete et al. 2002). Mantis has a very important ecological role in the suppression of herbivorous insect populations including some agriculture pests with very few species, with biological control impact (Symondson et al. 2002).

Although it is a large desert country with sand dunes form 96% of its land (Hoath 1993), Egypt constitutes the highest biodiversity of order Mantodea in the Palaearctic Region (Mohammad et al. 2011; Enan et al. 2017). The total number of Mantodea species in Egypt is 60 species under 21 genera and 4 families (Empusidae, Eremiphilidae, Mantidae, and Tarachodidae) (Nasser 2010). This diversity is attributed to the location of the country. The presence of the Nile Valley connects the tropical fauna to the Mediterranean coast that allows animals including mantis to cross the Sahara Desert. Also, it separates the desert into small habitats allowing the flourish of many desert species such as *Eremiaphila* in the country (Battiston et al. 2010). Although the diversity of Mantodea in Egypt is high, the number of individuals previously

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collected was low (Sawaby et al. 2010). However, there were several studies concerning mantis taxonomy in Egypt; those discussing their distribution and ecological parameters governing such distribution are scared (Sawaby et al. 2010).

Nowadays, ecology relies on data science through most of its research areas (Hirzel et al. 2002; Moulin 2020). Distribution modeling has been considered as an important technique to formalize the link between the species and their geographical surroundings, in particular, to quantify the parameters which govern their presence (Peterson et al. 2007; Abutaleb et al. 2019). In recent years, such an approach received increased attention to assess the geographical distribution of species and was applied to the fields of ecology and conservation biology (Ganeshaiah et al. 2003; Levine et al. 2004; Ma'moun et al. 2017; Hosni et al. 2020).

Analysis of biogeographical data of predator or parasite species helps in studying their distribution in different regions and provides an essential tool for conservation planning and biological control strategies (Brown and Lomolino 1998; Ladle and Whittaker 2011; Nasser et al. 2015, 2019a, b; Keerthi et al. 2020). There are several insect groups which face neglection in their ecological study in Egypt (Abutaleb et al. 2019; Adly et al. 2019). Accordingly, the present study was conducted and focused on calculating the zoogeographical affinities of mantises and modeling the distribution pattern of Mantodea as a group in different Egyptian ecological zones, estimating species richness, analyzing bioclimatic, and geographical factors that contribute to such distribution using GIS and for better understanding the ecology of these charismatic predators.

Materials and methods

Study area

The study was conducted in Egypt (31° 12′ 20.7108′′ N; 29° 55′ 28.2936′′ E), which located in the northeastern corner of Africa, covering an area of 1,001,449 km^2. Egypt is divided into eight ecological regions: coastal strip, Lower Nile Valley (Nile Delta), Upper Nile Valley, Fayoum Basin, Eastern Desert, Western Desert, Sinai, and Gebel Elba (El-Hawagry and Gilbert 2014).

Mantodea data and sampling

The existing data of Mantodea species were obtained from the biodiversity database, including Project Noah (http://www.projectnoah.org), the Global Biodiversity Information Facility (http://www.gbif.org/), museum collections of the State Museum of Natural History Karlsruhe, Ain Shams University, Cairo University, Egyptian Society of Entomology, Al-Azhar University, and the Ministry of Agriculture, from the literatures (Giglio-Tos 1921; Marshall 1975; Ehrmann 1996; El-Moursy et al. 2001; Mohammad et al. 2011), and specimens collected during a large series of field trips in different ecological zones (Alexandria, Aswan, Faiyum, Hurghada, Gabal Alba Protected Area, North Coast, Sant Katherine, and Siwa) by the second author (2008 to 2010) and first author at 2017 (El Qoseir, Quena, Ras Mohammed National Park, Sharm El-Sheikh, Wadi Rayan Protected Area). Visual inspection of vegetation and swiping net were used as the main method to collect Mantodea samples during the fieldwork (Supplementary 1).

Ecological zones affinity analysis

The number of observations and species in the database was tabulated separately for each ecological zone. The number of observations per species was calculated to estimate the intensity of collection by an ecological zone that indicates the species richness in each of them. In addition, to study the similarity of species composition among such ecological zones, we used the Sørensen-Dice coefficient or Sørensen similarity index

[S_s = 2a/(b + c) where a = number of species in both zones, b = number of species in the 1^{st} zone, and c = number of species in the 2nd zone] which ranges from 0 to 1 (Dice 1945; Sørensen 1948). The dendrogram was constructed according to the unweighted pair-group mean arithmetic method (UPGMA) using the PAST (Paleontological Statistics Version 3; Hammer et al. 2001) computerized software.

Ecological modeling of Mantodea

The present climatic data were downloaded from the WorldClim database with a spatial resolution of 2.5 min (http://www.worldclim.org) while altitude, aspect, and slope were calculated using ArcGIS 10.3. All these bioclimatic layers were clipped to match the dimension of Egypt by using ArcGIS software V. 10.3. In this study, 19 climatic and 3 topographical variables were used to estimate the current status of Mantodea as a group (Table 1). No elimination of any bioclimatic factors has made as we apply them to the heterogenous group as Mantodea.

Maximum entropy model (MaxEnt) is one of the very important tools that is applied for conducting species distribution modeling due to its ability to fit in low sample size and easy to produce an accurate model (Phillips et al. 2006; Peterson et al. 2007; Elith and Leathwick 2009). When a low number of sample localities are available, MaxEnt can predict the species distribution modeling more efficiently than other ecological niche models. It can produce a habitat suitability map, and the importance of individual environmental variables can be evaluated using jackknife test (Anderson et al. 2006; Hernandez et al. 2008). Moreover, Maxent facilitates the

Table 1 Environmental and topographical variables used in Maxent to predict the current habitat suitability distribution of Mantodea species

Variable	Description
Bio 1	Annual mean temperature
Bio 2	Mean diurnal range (mean of monthly max temp – min temp)
Bio 3	Isothermality (bio2/bio7) × 100
Bio 4	Temperature seasonality (standard deviation × 100)
Bio 5	Max temperature of the warmest month
Bio 6	Min temperature of the coldest month
Bio 7	Temperature annual range
Bio 8	Mean temperature of the wettest quarter
Bio 9	Mean temperature of the driest quarter
Bio 10	Mean temperature of the warmest quarter
Bio 11	Mean temperature of the coldest quarter
Bio 12	Annual precipitation
Bio 13	Precipitation of the wettest month
Bio 14	Precipitation of the driest month
Bio 15	Precipitation seasonality (coefficient of variation)
Bio 16	Precipitation of the wettest quarter
Bio 17	Precipitation of the driest quarter
Bio 18	Precipitation of the warmest quarter
Bio 19	Precipitation of the coldest quarter
Altitude	Altitude in degrees
Aspect	Aspect ratio
Slope	Slope

replication run that allows cross-validation and tests the model performance by repeating subsampling (Adhikari et al. 2012).

To produce a model for the range of the species, this model takes input as a set of environmental layers and a set of occurrence records. 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 the model accuracy. Twenty replicate runs were assigned to generate the average, maximum, minimum, and median of the distribution range of Mantodea species. The contributions of all variables were determined by producing the jackknife approach in Maxent software (Pearson et al. 2007).

Model evaluation

The performance efficiency was determined by several statistical tests. The area under curve (AUC) values of receiver operating characteristic (ROC) curves (Phillips et al. 2006; Peterson et al. 2008). In general, AUC is between 0.5 and 1 where an AUC of 0.5 indicates that the model did not perform better than random, values between 0.5 and 0.7 indicate poor prediction ability, values of 0.7–0.9 indicate moderate prediction, and values above 0.9 indicate strong prediction (Swets 1988). Also, the model predictions were tested using the partial ROC (pROC) statistics to test model robustness (Peterson et al. 2008; Okely et al. 2020). Finally, the True Skilled Statistics (TSS) was made to assess the accuracy of the models from the logistic values of background prediction. The values of the test range from − 1 to 1 and if it is close to negative or zero imply that the distribution is not much better than random; on the other hand, the values close to 1 indicate an intimate relationship between the model prediction and actual distribution (Hosni et al. 2020).

Seasonality analysis

The analysis of seasonality data of the common 14 genera of Mantodea was based on the data of collected samples and several previous literatures (Giglio-Tos 1921; Marshall 1975; Ehrmann 1996; El-Moursy et al. 2001; Battiston et al. 2010; Mohammad et al. 2011).

Results and discussion

The analysis of Mantodea records in the Egyptian fauna showed that *Blepharopsis mendica* has the highest number of records with 90 occurrence points. On the other hand, 23 species *Empusa fasciata*, *Dilatempusa aegyptiaca*, *Eremiaphila anubis*, *Eremiaphila berndstiewi*, *Eremiaphila brevipennis*, *Eremiaphila cairina*, *Eremiaphila hedenborgii*, *Eremiaphila lefebvrii*, *Eremiaphila luxori*, *Eremiaphila nilotica*, *Eremiaphila rohlfsi*, *Eremiaphila rufipennis*, *Elaea gestroi gestroi*, *Elaea marchali*, *Elaea solimani*, *Ischnomantis perfida*, *Microthespis dmitriewi*, *Oxyothespis dumonti*, *Sinaiella nebulosa*, *Sinaiella sabulosa*, *Heterochaeta pantherina*, *Paroxyophthalmus*

Table 2 Mantodea distribution by the ecological zone in Egypt. Number of observations (obs), species, and ratio of observations to species

Ecological zone	Obs	Species	Obs/species
Coastal Strip	33	17	1.9
Lower Nile Valley (including the Delta)	184	23	8
Upper Nile Valley	20	12	1.7
Fayoum Basin	18	7	2.6
Eastern Desert	48	22	2.2
Western Desert	58	25	2.3
Sinai	86	19	4.5
Gebel Elba	3	2	1.5
Total	450	127	24.7

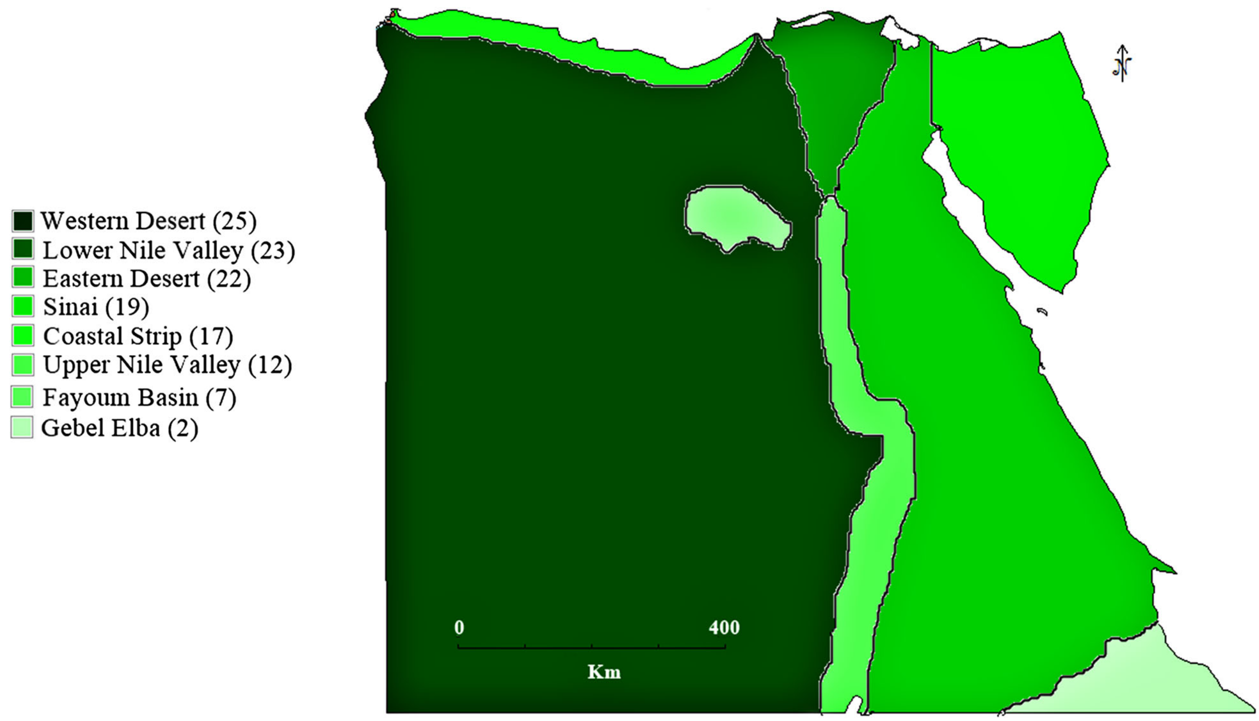

Fig. 1 Map of Egypt showing the eight ecological zones and the total number of Mantodea species collected from each zone

collaris, and *Tarachodes (Chiropacha) gilvus* were recorded only once.

Mantodea species occur in the eight ecological zones of Egypt (Table 2, Fig. 1). Four ecological zones (Lower Nile Valley and Delta, Sinai, Western Desert, and Eastern Desert) accounted 83.6% of the records in the database, while the other four zones (Coastal Strip, Upper Nile Valley, Fayoum Basin, and Gebel Elba) accounted 16.4% of the records. The Western Desert has by far the highest number of species (25 species, 19.7%), and Gebel Elba has the lowest number (2 species, 1.6%) (data from Gebel Elba is not accurate as visiting this zone is very difficult and maybe not allowed for security reasons). The observations per species ratios strongly varied across the different ecological zones (Table 2). The ratio was very high in Lower Nile Valley (8) and Sinai (4.5) indicating that these two ecological zones have been explored more intensively than the other zones.

The Egyptian ecological zones vary in their compositional similarity to each other (Table 3). The highest similarity was between Coastal Strip and the lower Nile Valley, while the lowest similarity was between Gebel Elba and the Western Desert. Similarities were lower between Gebel Elba and any of the other zones. Also, the Eastern Desert and Western Desert have similarities to one another, forming one cluster (Fig.

Table 3 The similarity of mantis faunas in the Egyptian ecological zones. The number of species shared between each pair of zones is given in the upper half of the table, and the Sørensen-Dice coefficient between each pair of zones is given in the lower half of the table

	Coastal strip	Lower Nile Valley	Upper Nile Valley	Fayoum Basin	Eastern Desert	Western Desert	Sinai	Gebel Elba
Coastal strip	–	10	5	6	6	11	8	1
Lower Nile Valley	0.55	–	7	6	9	10	11	1
Upper Nile Valley	0.34	0.4	–	4	3	7	4	1
Fayoum Basin	0.5	0.4	0.42	–	4	6	5	1
Eastern Desert	0.35	0.4	0.18	0.28	–	10	5	2
Western Desert	0.52	0.41	0.38	0.38	0.42	–	5	1
Sinai	0.44	0.52	0.25	0.38	0.3	0.27	–	1
Gebel Elba	0.1	0.08	0.14	0.22	0.16	0.07	0.1	–

2). The habitat suitability of Mantodea in Egypt was fragmentary and focused in different distinct ecological zones. Areas with a high probability of Mantodea were predicted in the Lower Nile Valley, Coastal Strip, Red Sea Coast, North-Eastern part of the country (Sinai), Luxor on Upper Nile valley, and South Sinai. There were also some predicted areas of Mantodea in the western part of the country including Siwa Oasis (Fig. 3).

The Western desert had the highest number of species, but the number of observations was low as compared to the Lower Nile Valley and Delta which had the highest number of observations. Because the number of observations and species tends to rise with collecting effort, the ecological zones with a low ratio (observation/species) would be the most places to find species that have not been discovered. The similarities between the eight ecological zones showed that Gabel Elba has the lowest similarities due to that it belongs to the Afrotropical Region. This result is compatible with the result of El-Hawagry and Gilbert (2014). The Eastern and Western Deserts have a high similarity to each other; this is due to that both form a part of the Sahara Desert.

The Maxent model for Mantodea as a group provided satisfactory results, with an AUC value of 0.887 for test and 0.954 for training which is higher than 0.5 of a random model. ENM for Mantodea species yielded predictions that gave an area under the curve (AUC) ratios above the null expectations in partial ROC analyses ($P < 0.001$), where the minimum, maximum, and mean pROC values are 1.4, 1.6, and 1.49, respectively. Also, the results of (TSS) show a high degree of confidently with a value of 0.872.

Altitude showed a higher effect on the distribution of Mantodea relative to the other variables (Fig. 4). It had the top contribution of 36.2% to the model. Temperature-related variables had 49.4% contribution to the model of which the mean temperature of the coldest quarter (bio11) gave the highest influence on the model with 16.2% (Table 4). Precipitation-related variables had a relatively small influence on the model with only 10.7% contribution. Among these variables' precipitation of the wettest month (bio 13) gave the highest influence on the model with 3.7% contribution. Slope and aspect had a small influence on the model with only 2.9% and 0.9%, respectively. The only variable that had no effect on the model was precipitation of the driest month (bio 14) with zero contributions (Table 4).

Our modeling showed that the Western Desert had a low habitat suitability to Mantodea species (Fig. 4). Although this result is unexpected, this may be due to the domination of genus *Eremiaphila* (a desert mantis) in such harsh environment. The lowest number of collected samples of this genus from the region

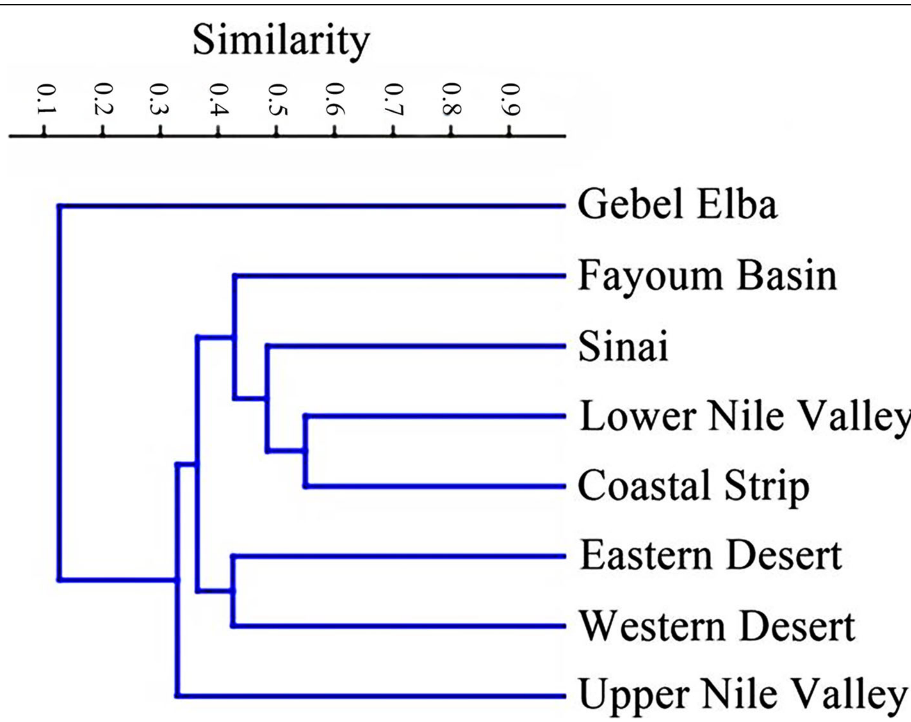

Fig. 2 Dendrogram of the similarity in species composition of the ecological zones

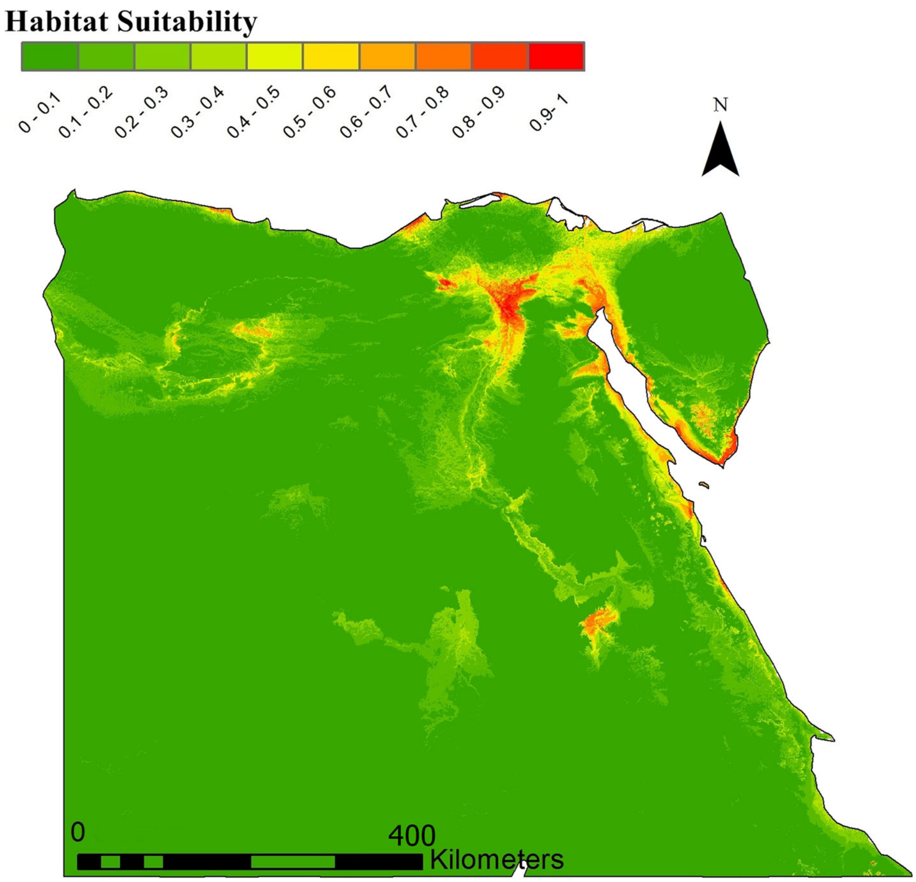

Fig. 3 Habitat suitability of Mantodea species in Egypt according to occurrence records

forms the main reason for such results. In general, the genus *Eremiaphila* faces a lack of representative samples in museums collection (Nasser 2010), and they are difficult to collect in the field as its species live in remote places of desert areas and mimic stones and sand (Preston-Mafham 1990). The results of our model (Fig. 4) are compatible with the ratio between observation/species (Table 2) which indicate that the Lower Nile Valley and Delta have a high habitat suitability with a high ratio. Also, coasts of the Mediterranean, Red Sea, and Sinai have a high suitability to Mantodea species. These areas receive the higher rainfall in the winter months (El-Hawagry 2002). This may explain the impact of precipitation of wettest month (bio 13) on the modeling of habitat suitability. Altitude forms the main factor that affects the distribution of Mantodea as a group and such an interesting upshot agrees with several previous publications concerning the group ecology (Shcherbakov and Savitsky 2015; Moulin et al. 2017).

The heterogeneity of ecological requirements of different species of mantis used in our model could form a limitation for the final results, but on the other hand, the final map gave us ideas about areas with high mantis concentration, the regions that need more surveillance efforts, an area that is very suitable for mantis as a potential biological control agent, and the part of mantis community that occupied conserved areas such as that found on in St. Catherine and NABQ-protected areas in Sinai. The final map gives an idea about the order—as a whole—not for a specific genus or species, especially the desert mantis that has somewhat completely different habitat than any other Mantodea group (Ranade et al. 2004).

Analysis of seasonality data of Mantodea genera (Fig. 5) indicated that *mantis* and *Sphodromantis* reach the adult stage in summer and overwinter as Ootheca, *Miomantis* present in the adult stage from spring to winter, *Rivetina* can be found as the adult stage from early summer to late autumn, *Severinia* seems to be present in the adult stage from winter to spring, *Sinaiella* can be found as the adult stage from early winter to late spring, *Heterochaeta* can be found in the adult stage during summer, *Empusa* and

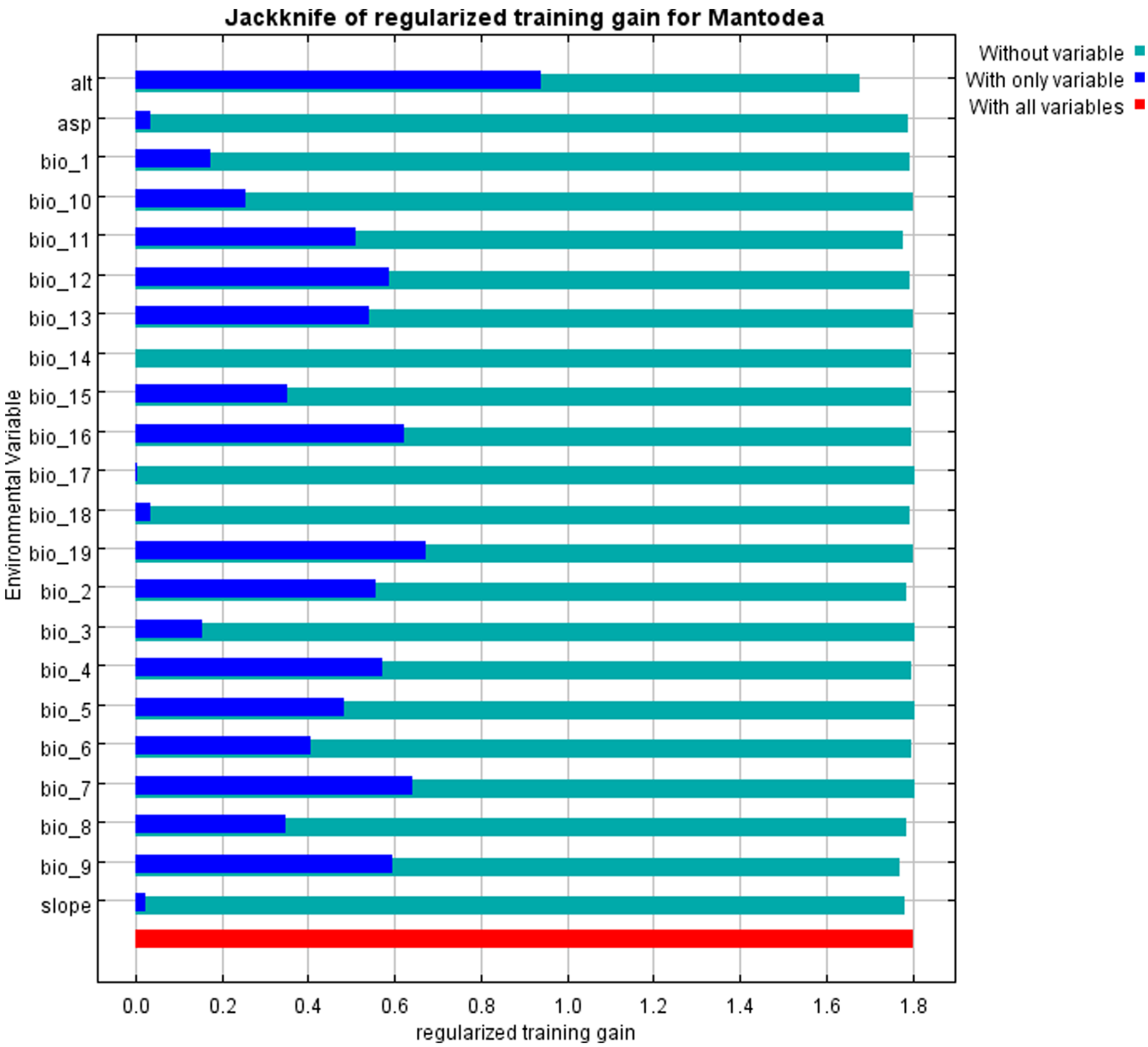

Fig. 4 Relative importance of environmental variables based on jackknife of regularized training gain in maxent model for Mantodea species, values shown are average over 20 replicate runs

Hypsicorypha overwinter as nymphs and adults can be found in late spring, *Iris* seems to be found as the adult stage in late summer and eggs hatch in spring, *Elaea* can be found as the adult stage from spring to summer, *Eremiaphila* and *Heteronutarsus* can be found almost throughout the year, and finally, *Blepharopsis* overwinters as a nymph and the adult can be found in spring.

Most of the mantis species have only one generation a year (Hogue and Powell 1980). The seasonality analysis of the common 14 genera indicated that 11 of them reach the adult stage in spring and summer and 3 genera (*Miomantis*, *Severinia*, and *Sinaiella*) live as the adult stage in winter and spring. Most mantis species preferred warm weather, and the hatching of their eggs usually depends on temperature (Hurd et al. 1995). This may explain why the impact of the mean temperature of the coldest quarter (bio11) on the modeling of habitat suitability is high as the temperature of winter months will greatly affect the hatching of the eggs and development of the nymphal stage.

Conclusion

The present study represents the first attempt to study the biogeography of Mantodea as a group in different ecological zones in Egypt. The way is still so far from getting a complete understanding of mantis habitat in the country, and great efforts are needed in monitoring

Table 4 The contribution percentage of the total 22 ecological and topographic layers in predicting the spatial distribution of Mantodea species in Egypt

Variable	Description	Contribution %
Bio 1	Annual mean temperature	2.8
Bio 2	Mean diurnal range (mean of monthly (max temp – min temp)	4.5
Bio 3	Isothermality (bio2/bio7) × 100	1.1
Bio 4	Temperature seasonality (standard deviation × 100)	1.4
Bio 5	Max temperature of the warmest month	5.9
Bio 6	Min temperature of the coldest month	0.7
Bio 7	Temperature annual range	7.8
Bio 8	Mean temperature of the wettest quarter	2.6
Bio 9	Mean temperature of the driest quarter	6
Bio 10	Mean temperature of the warmest quarter	0.4
Bio 11	Mean temperature of the coldest quarter	16.2
Bio 12	Annual precipitation	1.7
Bio 13	Precipitation of the wettest month	3.7
Bio 14	Precipitation of the driest month	0
Bio 15	Precipitation seasonality (coefficient of variation)	0.9
Bio 16	Precipitation of the wettest quarter	1.5
Bio 17	Precipitation of the driest quarter	0.3
Bio 18	Precipitation of the warmest quarter	0.4
Bio 19	Precipitation of the coldest quarter	2.2
Altitude	Altitude in degrees	36.2
Aspect	Aspect ratio	0.9
Slope	Slope	2.9

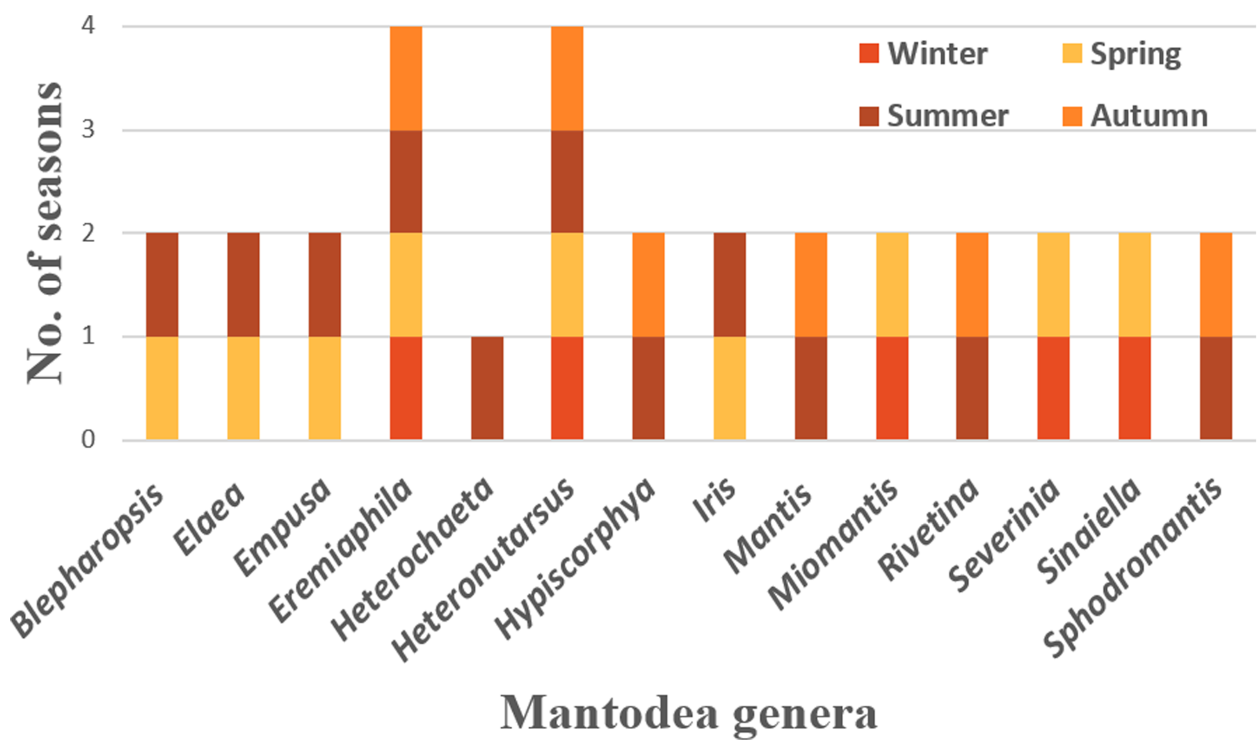

Fig. 5 Histogram illustrating the seasonality appearance of the adult stage of most common genera of Mantodea in Egypt

their species in unexplored regions such as Gebel Elba. Some interesting species of Mantodea such as *Blepharopsis mendica* need more attention throughout their whole range including Egypt. Also, species of the interesting genus *Eremiaphila* need more intensive studies. Our results here form only the beginning step on a better understanding of the Mantodea oasis of the Palaearctic Region (Egypt).

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s41938-020-00336-8.

Additional file 1. Mantodea records of Egypt. The sheet contains 428 records of Mantodea with their coordinates and the source of each record.

Abbreviations

Maxent: Maximum entropy; GIS: Geographical Information System; UPGMA: Unweighted pair-group mean arithmetic method; PAST: Paleontological statistics; AUC: Area under the curve; ROC: Receiver operating characteristics; TSS: True skill statistics; ENM: Environmental niche model

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Authors' contributions

MO, MN, and SA contributed to the conceptualization, experimentation, and original draft writing. MO and MN contributed to the fieldwork. SG and RA contributed to the statistical analysis, manuscript editing, and reviewing. All authors contributed to and accepted the manuscript in its final version.

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Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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