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Ecological Niche Modeling of *Ommatissus Lybicus* (Hemiptera: Tropiduchidae) De Bergevin

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Abstract

Date palm hooper is one of the most important pests on date palms with many highly diverged populations varied in damaging rate and preferring host cultivar. Current and potential geographic distribution of date palm hopper, *Ommatissus lybicus* (de Bergevin; Hemiptera: Tropiduchidae) in Iran was modeled using the Maxent procedure. Point sampling data sets included latitude, longitude, and altitude and were augmented with data on 19 bioclimatic variables retrieved from WorldClim dataset for use as predictor variables in Maxent. Maxent results demonstrated that northwest Sistan-Baluchestan, east, south and southeast Kerman, northeast and northwest Hormozgan and small districts of Bushehr provinces are hot spot habitats for *O. lybicus* in Iran. Jackknife analysis revealed that precipitation of warmest quarter was the most influential explanatory variable in determining distribution of *O. lybiucs* in Iran. Moreover, curve response and frequency distribution analyses revealed that annual mean temperature was the most predictive factor of the distribution of *O. lybicus*. Discontinuity in predicted hot spot habitats of *O. lybicus* was consistent with the genetic structure recorded for this species. Our study represents valuable information that can inform pest management strategies aimed at preventing population expansion and niche shift.

Key words: dubas bug, hot spot, Maxent, jackknife analysis, explanatory variable

Knowledge of species distribution is an important tool in management strategies of agricultural pests (Peterson et al. 2005, Phillips et al. 2006, Tognelli et al. 2009) According to niche theory, species ranges are restricted by physiological tolerances (fundamental niche), as well as biotic interactions and dispersal barriers (realized niche) (Tingley et al. 2014). The fundamental niche is defined as the environmental space in which fitness is one or greater. The realized niche is more restricted than the fundamental niche and is obtained by including biotic interactions (Santana et al. 2008, Varghase et al. 2010). Niche models may predict species distribution when no complete inventory of species occurrence is available (Tognelli et al. 2009). These models are increasingly being used to produce detailed distribution and habitat suitability maps (Batista and Gurgel-Goncalves 2009, Tognelli et al. 2009, Warren and Seifert 2011). Such models may be used to predict the geographic distribution of a species in unexplored regions, or for scenarios of future or past climatic conditions (Tognelli et al. 2009). Furthermore, this approach has been widely used to address issues in ecology, biogeography, evolution, conservation biology, disease transmission, species invasion and the effect of climate change (Tognelli et al. 2009, Varghase et al. 2010, Alvarado-Serrano and Knowles 2014). Predictive models have been applied to estimate species distribution in a diverse array of arthropods like *Clitarchus hookeri* (Buckley et al. 2010), *Solenopsis invicta* (Peterson and Nakazawa 2008), hemipteran insects (Carolan et al. 2014), orchid bees (Silva et al. 2014), *Ixodes ricinus* (Linnaeus; Acari: Ixodidae) (Porretta et al. 2013), *Rhodnius neglectus* (Lent; Hemiptera: Reduviidae: Triatominae) & *Rhodnius nasutus* (Stal; Hemiptera: Reduviidae: Triatominae) (Batista and Gurgel-Goncalves 2009), *Hishimonus phycitis* (Distant; Hemiptera: Cicadellidae) (Shabani et al. 2013) and *Diaphorina citri* (Kuwayama; Hemiptera: Liviidae) (Lashkari et al. 2013).

Environmental (or ecological) niche models (ENMs) are a class of methods in which occurrence data is modeled in conjunction with environmental data (Warren and Seifert 2011). ENMs have become increasingly important tools for analyzing distribution-based data (Groff et al. 2014). ENMs are mostly used to evaluate the relative suitability of habitat known to be occupied by the species, study the relative suitability of habitats in geographic areas not known to be occupied by the species, assess changes in the suitability of habitat over time given a specific scenario for environmental change and to estimate the species niche (Warren and Seifert 2011, Groff et al. 2014).

The maximum entropy modeling technique (Maxent) is one of the ENMs methods which have been abundantly applied in modeling of species distribution (Phillips et al. 2006). Maxent is a general approach that enables probability distributions to be estimated from incomplete information (Phillips et al. 2006). In addition, it can model interaction relationships among variables and estimate species distribution (Phillips et al. 2006). The roles of temperature, precipitation, elevation and other bioclimatic variables are reliably estimated by Maxent (Phillips et al. 2006). The efficiency of model can be highly varied based on quality and quantity of input data like type of species, sampling site and number of sampling points (Tognelli et al. 2009).

The date palm hopper, *Ommatissus lybicus* (de Bergevin; Hemiptera: Tropiduchidae), also known as dubas bug (Thalhouk 1977), is one of the most important pests of date palm. It has been reported from Asia to Africa and can cause severe damage in date palms by sucking the phloem sap and excreting honeydew. Both the nymphs and adults of *O. lybicus* suck the sap from leaflets and midrib of fronds, resulting in both direct and indirect damage (Wilson 1986, 1988; Bagheri et al. 2016). *O. lybicus* is bivoltine and has two distinct generations per year (Bagheri et al. 2016) and high potential to cause economically damage if it is not managed properly.

Table 1. Environmental variables and their relative contribution for niche modeling of *O. lybicus* in Iran

Bioclimatic variables	Variable code	Percent contribution
Annual mean temperature	Bio1	2.7
Mean diurnal range (max temp-min temp) (monthly average)	Bio2	0.7
Isothermality (Bio1/Bio7) * 100	Bio3	0.4
Temperature seasonality (Coefficient of variation)	Bio4	2.2
Max temperature of warmest period	Bio5	0.3
Min temperature of coldest period	Bio6	0.1
Temperature annual range (Bio5-Bio6)	Bio7	0
Mean temperature of wettest quarter	Bio8	2.3
Mean temperature of driest quarter	Bio9	1.6
Mean temperature of warmest quarter	Bio10	2.3
Mean temperature of coldest quarter	Bio11	0
Annual precipitation	Bio12	0.2
Precipitation of wettest period	Bio13	0.1
Precipitation of driest period	Bio14	10.1
Precipitation seasonality (coefficient of variation)	Bio15	9.8
Precipitation of wettest quarter	Bio16	0
Precipitation of driest quarter	Bio17	0.4
Precipitation of warmest quarter	Bio18	46.5
Precipitation of coldest quarter	Bio19	18.1
Altitude		2.3

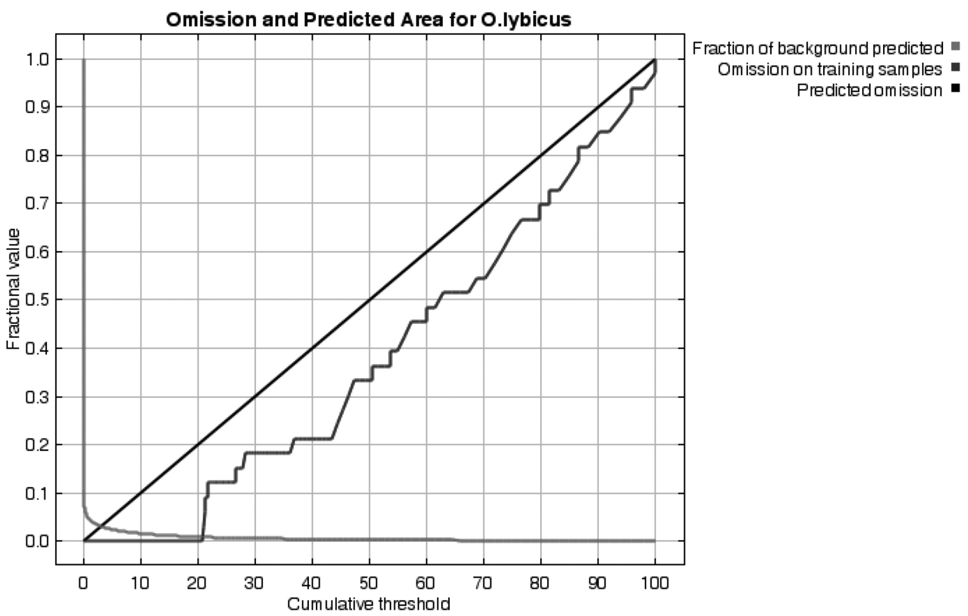

Fig. 1. The picture shows the omission rate and predicted area as a function of the cumulative threshold. Close distance of omission rate with predicted omission revealed fitness of the Maxent model.

For instances, in a severe *O. lybicus* outbreak in Egypt, it caused $400,000 loss in 1935 and in another case in Morocco, destroyed 12 million date palms during two decades and consequently decreased the date production down to zero (Wilson 1986, Bassim 2003). Existing a lot of documents dealing with applying various insecticides either from their mode of action or their application procedure for controlling *O. lybicus*, indicating high economic importance and damaging rate of this pest on date palms (Wilson 1986, Askari and Bagheri 2005).

It comprises many allopatric populations (Bagheri et al. 2017), that show genetic variation within and among populations (Bagheri et al. 2018). However, no information is currently available regarding ecological niche of *O. lybicus* in Iran.

The aims of this study were to 1) plot ecological niche modeling of *O. lybicus* in Iran, 2) determine which bioclimatic factors play a key role in *O. lybicus* distribution, 3) studying the Effective factors in determination of realized niche and

Materials and Methods

Ecological Niche Modeling

The current and potential geographic distribution of *O. lybicus* in Iran was modeled using the maximum entropy method of ecological niche modeling (Phillips et al. 2006).

Data on latitude, longitude, and altitude were available for 421 sites within the distributional of *O. lybicus* in Iran. In addition, we obtained data on 19 temperature and precipitation variables from WorldClim global climate data with 30 s (1 km^2) resolution (Hijmans et al. 2005; Table 1). These data were used for ecological niche modeling of *O. lybicus* using Maxent ver. 3.3.3a (Phillips et al. 2006) and related Geographic Information System (GIS) software. The sixfold cross validation technique was used to prepare the model, using a maximum of 500 iterations, 10,033 background points as pseudo-absence and a convergence threshold of 0.00001. The predictive maps were constructed by entering the latitude, longitude and

Table 2. Geographic coordinate, prevalent date palm cultivars, infestation level and chemical pest control in main sampling sites of *O. lybicus*

Province	District area	Latitude	Longitude	Altitude (m)	Main cultivar	Infestation level	Chemical control	Aggressive behavior
Sistan-Baluchestan	Saravan	27° 22′ N	62° 20′ E	1,160	Mazafati	Low	-	-
Kerman	Bam	29° 6′ N	58° 21′ E	985	Mazafati	High	+	+
Kerman	Shahdad	30° 25′ N	57° 42′ E	468	Mazafati, Zahdi	High	+	+
Kerman	Jiroft	28° 22′ N	58° 00′ E	717	Mazafti	Low to moderate	-	-
Hormozgan	Roudan	27° 27′ N	57° 11′ E	200	Mordasang	Low	-	-
Hormozgan	Minab	27° 09′ N	57° 04′ E	16	Mordasang	Low	-	-
Hormozgan	Abu Musa	25° 53′ N	55° 02′ E	9	Mordasang	Low	-	-
Hormozgan	Fin	27° 37′ N	55° 53′ E	325	Khasi, Khunizi	High	+	periodical
Hormozgan	Tezerj	28° 16′ N	55° 40′ E	1,200	Piarom	High	+	periodical
Fars	Jahrom	30° 28′ N	53° 33′E	1,045	Shahani	Moderate	+	-
Fars	Ghire Karzin	28° 25′ N	52° 59′ E	771	Zahdi	High	+	periodical
Bushehr	Borazjan	28° 46′ N	51° 28′ E	350	Kabkab	High	+	periodical
Khuzestan	Behbahan	30° 35′ N	50° 14′ E	326	Khasi, Kabkab	Moderate	-	-
Kermanshah	Ghasre Shirin	34° 31′ N	45° 34′ E	393	Zahdi, Ashrasi	low	-	-

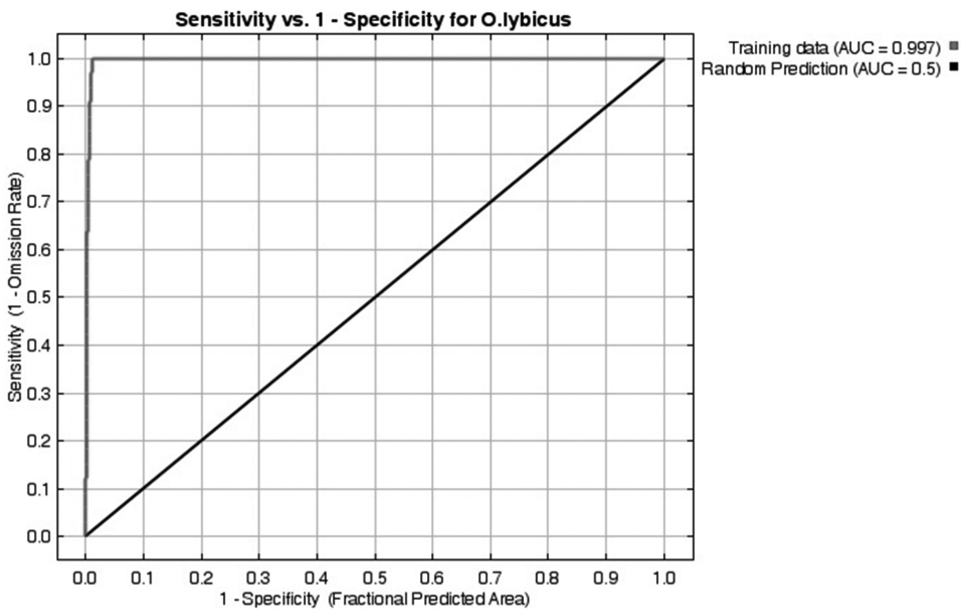

Fig. 2. Receiver operating curve analysis in niche modeling of *O. lybicus* in Iran.

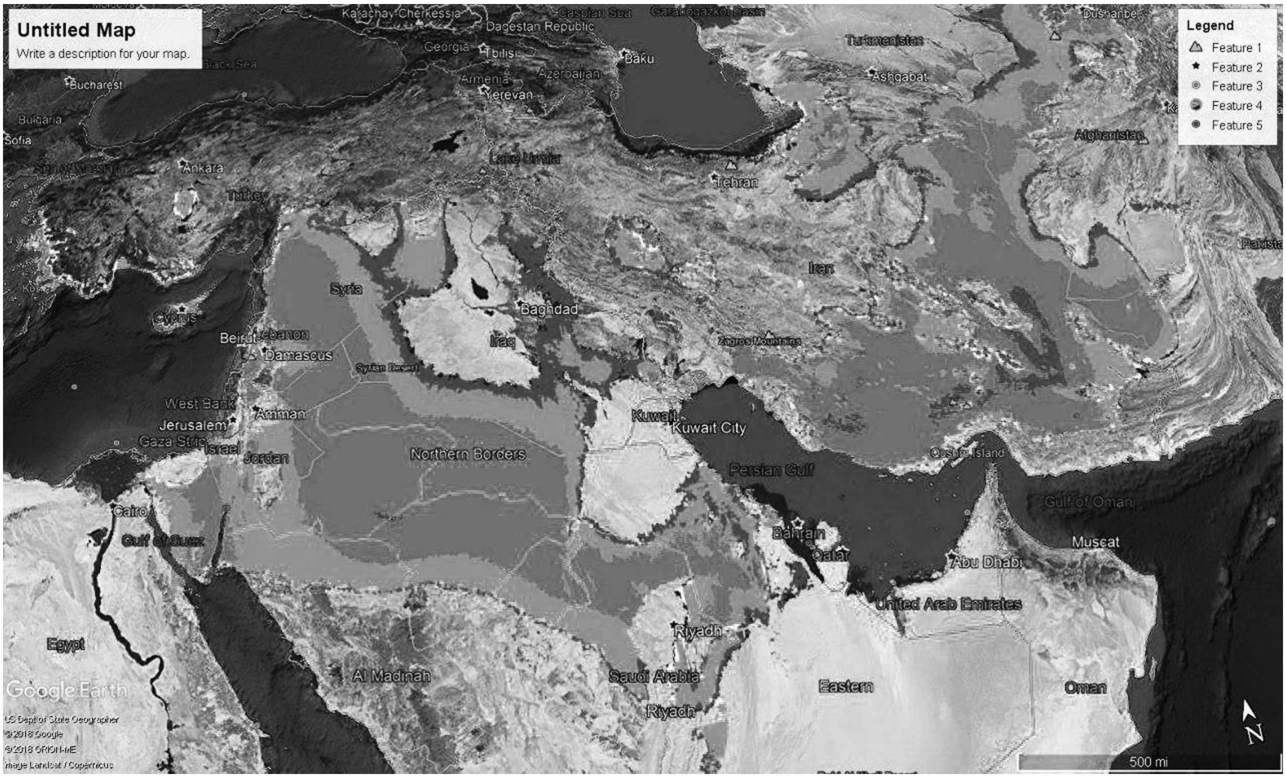

Fig. 3. Current and potential distribution of *O. lybicus* in Iran using Maxent model. The black color shows hot spot regions with high probability of *O. lybicus* occurrenes. The dark gray color indicates moderate probability of occurrence. The gray colors show no appropriate regions for *O. lybicus*.

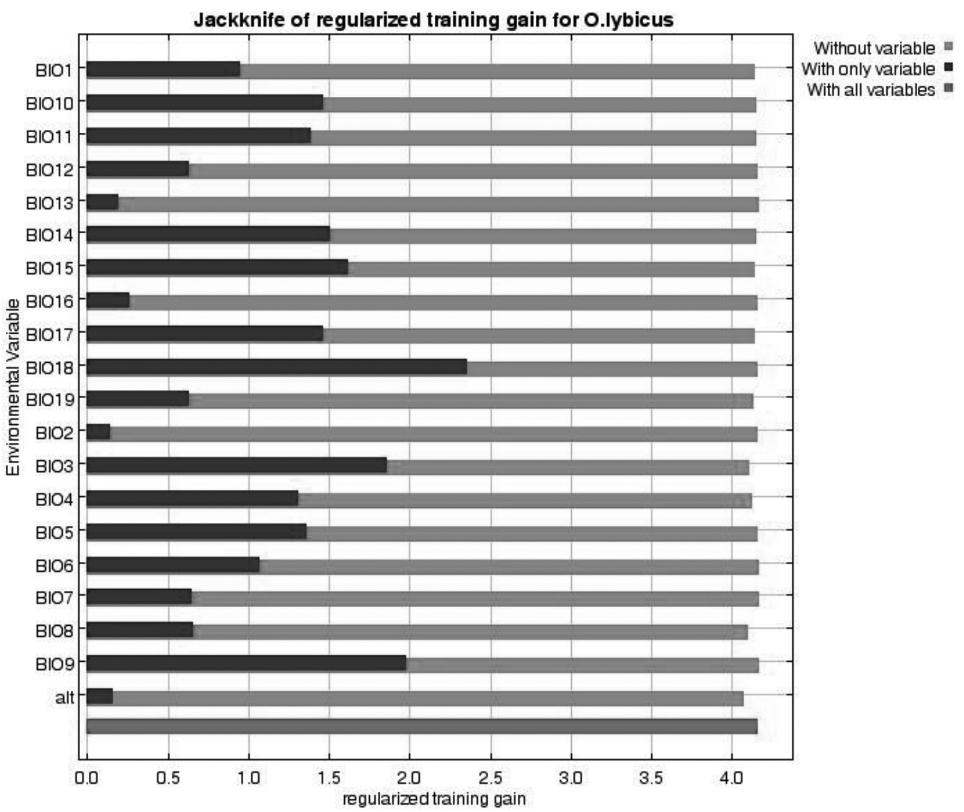

Fig. 4. Jackknife analysis of environmental variables affecting on *O. lybicus* distribution model in Iran.

altitude values of the 421 *O. lybicus* sampling sites into Maxent. These were analyzed in conjunction with bioclimatic variables as predictor variables. The resulting model was evaluated with the area under the receiver operating characteristic (ROC) curve (Graham and Hijmans 2006, Phillips et al. 2006). The area under the curve (AUC) statistic is a threshold-independent measure for assessing model performance (Phillips et al. 2006). AUC values range from 0.5 (model predicts occurrences no better than random) to 1.0 (perfect prediction) (Araujo et al. 2005, Phillips et al. 2006). Jackknife analysis was used to estimate the contribution of each variable to the performance of the model. The final map was visualized in ArcGIS 9.3 (http://www.webhelp.esri.com/arcgisdestop/9.3/index.html).

Factors Determining Realized Niche

To investigate the factors that determine the realized niche of *O. lybicus* in Iran, 42 orchards from 14 main date palm growing regions in Iran were sampled. For each orchard, six date palms were randomly chosen and five leaflets from each tree (totally 30 leaflets per orchard) were detached and number of eggs counted. Infestation levels were categorized into high, moderate or low based on the mean number of eggs per leaflet (exceeding 10 eggs per leaflet, 5–10 eggs per leaflet and fewer than 5 eggs per leaflet, respectively) (Behdad 1991). For each orchard, we recorded geographical coordinates, type of date cultivar and whether or not chemical control against *O. lybicus* was applied.

Results

Our data showed variable *O. lybicus* infestation levels in the sampled date orchards. Chemical pesticides was the most common practice for controlling the pest in highly infested orchards. Furthermore, infestation level of *O. lybicus* was not related to date variety and in the hot spot habitats, *O. lybicus* was found on different date cultivars.

We predicted suitable habitat niches and the species distribution of *O. lybicus* in Iran using environmental niche modeling. The average map was chosen as the final output. Average test AUC for the replicate runs was 0.997 ± 0.066 SD. The ROC curves revealed the significance of the predictor variables (Figs. 1 and 2).

Figure 3 shows the predicted geographical distribution of *O. lybicus* in Iran as calculated by model. The areas in red to orange indicate hot spot and high suitable habitats for *O. lybicus*, respectively. The remaining areas have little or no suitability for *O. lybicus*. Northwest Sistan-Baluchestan, east, south and southeast Kerman, northeast and northwest Hormozgan and small districts of Bushehr provinces were found to be the hot spot habitats for *O. lybicus* in Iran. In addition, the climatic niche model predicted suitability of

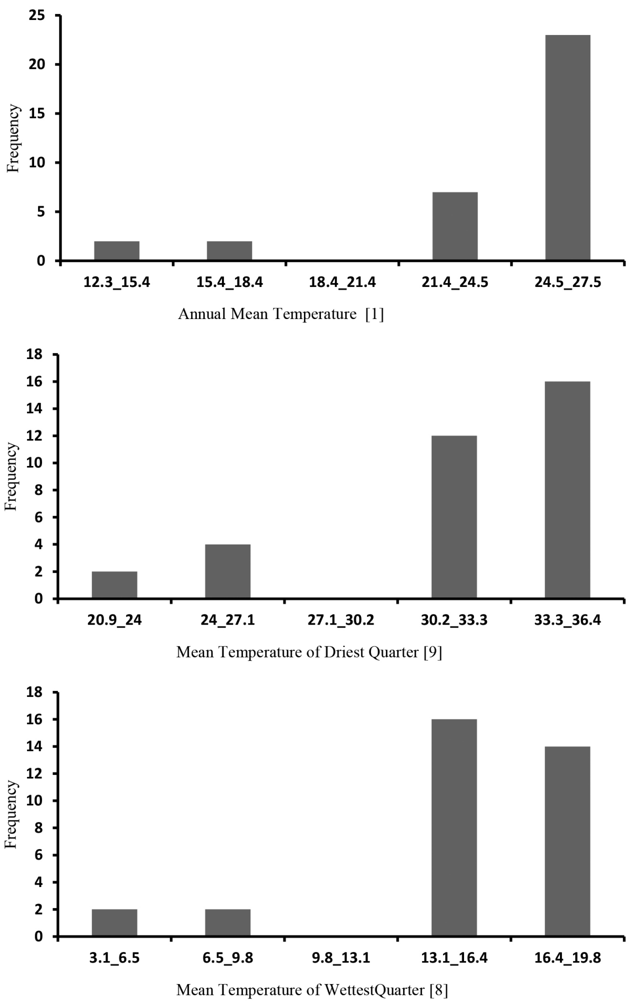

Fig. 5. Effect of Bio1, Bio9, and Bio8 variable factors on increasing distribution of *O. lybicus* in Iran.

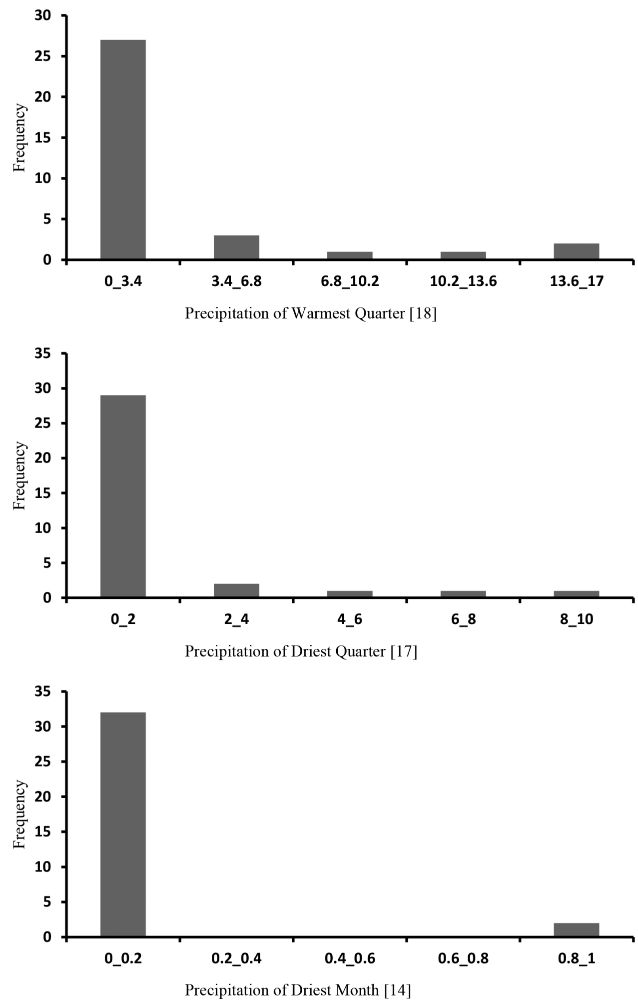

Fig. 6. Effect of Bio18, Bio17, and Bio14 variable factors on decreasing distribution of *O. lybicus* in Iran.

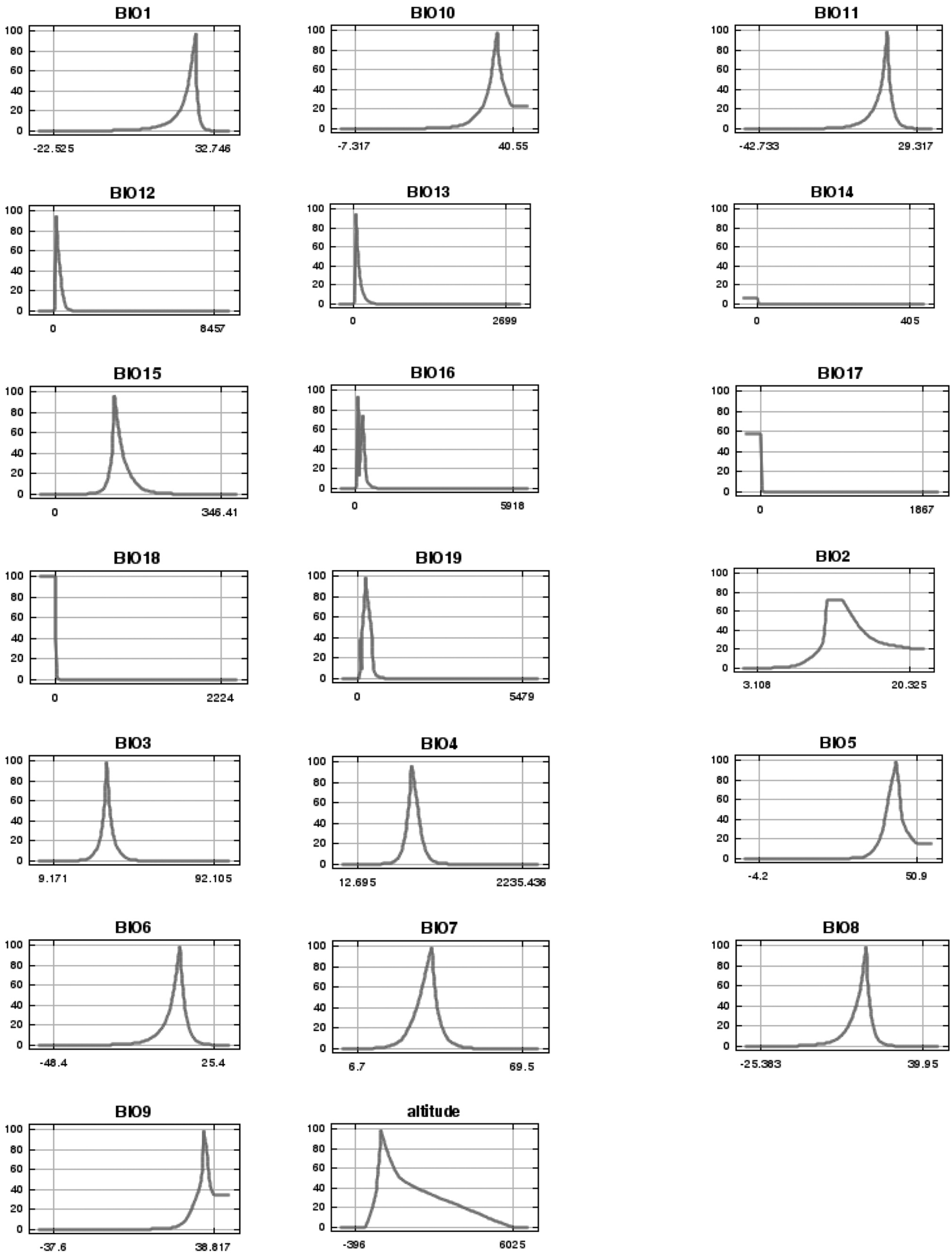

Fig. 7. Effect of 19 bioclimatic variables and altitude on predicted distribution of *O. lybicus* in Iran.

South Khorasan, Kermanshah, Khuzestan, as well as some parts of Yazd, all parts of the Sistan-Baluchestan, Kerman, Hormozgan and Fars provinces for residing and activity of *O. lybicus*.

According to the jackknife and variable contribution analysis, precipitation during the warmest quarter (Bio18) contributed most to the niche model of *O. lybicus*. Afterwards, mean temperature of driest quarter (Bio9) and isothermality (Bio3) contributed most (Fig. 4). Mean diurnal range (Bio2) was of least importance in determining *O. lybicus* distribution (Fig. 4). Both the curve response and histograms showed the dependence of the predicted habitat on both the selected variable and the dependences that were induced by correlation between the selected variable and other variables (Figs. 5–7). It was revealed that the variables annual mean temperature (Bio1), mean temperature of driest quarter (Bio9) and mean temperature of wettest quarter (Bio8) were the most determinant variables in estimating the suitability of *O. lybicus* niches. Increased temperatures resulted in wider ecological niche of *O. lybicus* (Figs. 5 and 7). By contrast, increased precipitation (Bio18, Bio17, and Bio14) decreased its ecological niches (Figs. 6 and 7).

Discussion

The results of this study represent a reliable model of the distribution of *O. lybicus* in Iran. Both the hot spots and predictive habitats for distribution *O. lybicus* predicted by Maxent were in accordance with real infestation of *O. lybicus* in the studied date orchards (Fig. 3 and Table 2). Moreover, the ROC curve (Fig. 1) showed the efficiency of predictor variables and Maxent in niche modeling of *O. lybicus* in which close distance of omission rate and predicted omission confirmed fitness of the Maxent model (Fig. 2).

Lack of continuity among hot spots can prevent gene flow among *O. lybicus* populations and bolster *O. lybicus* diversification. These results are in line with the findings of Bagheri et al. (2016, 2017, and 2018) who showed deep genetic and behavioral differences between *O. lybicus* populations. Similar results were obtained by Shabani et al. (2013) and Lashkari et al. (2013) who showed climatical barriers limit distribution of *Hishimonus phycitis* and *Diaphorina citri* (vectors of witches broom disease of lime and Huanglongbing diseases, respectively) and may result in more their diversification.

There was a positive correlation between habitat suitability and annual mean temperature. Increased annual mean temperature increased probability of a place to be suitable for distribution and establishment of *O. lybicus*. Accordingly, the Maxent model marked Hormozgan and Kerman provinces as the hot spots for establishing *O. lybicus*. These two provinces have hot and humid summers and temperate winters. This finding was confirmed with real documented reports relating high density and infestation rate of *O. lybicus* in these provinces, which has forced farmers to control it by heavy pesticide application (Table 2).

The Maxent model showed all parts of Bushehr, Fars, Hormozgan, Kerman, Sistan-Baluchestan, and South Khorasan provinces to be suitable for establishing and causing damage by *O. lybicus*. Nevertheless, there are many date palm orchards in these areas in which *O. lybicus* is lacking or has very low density (Table 2). For example, *O. lybicus* occurs only in very low density in Ghasre Shirin, some parts of Khuzestan, Minab, Roudan, and south of Sistan-Baluchestan, rendering its monitoring in these regions difficult. It seems that its realized niche has been limited by biotic and abiotic factors, such as human activities, natural enemies, competitors, and geographical barriers (Panzacchi et al. 2015). For instance, it has been shown that allopatric populations of *O. lybicus* differ significantly from each other in terms of genetic pattern and life history traits (Bagheri et al. 2016). Therefore, the populations with higher growth parameters may reside more rapidly upon introducing to a new habitat especially when the other biotic restricting factors are lacking. Moreover, various date palm varieties with different genetic pattern are present in the different date producing areas (Taghinezhad 2015), which may influence life history traits and establishment of *O. lybicus* (Mahmoudi et al. 2015). Furthermore, cultural and managing practices may affect realized niche. For example, *O. lybicus* may be subjected to the various control practices including heavy pesticide usage (Table 2).

The Maxent model also revealed that temperature and precipitation had different effects on *O. lybicus* distribution. While increased temperature extended *O. lybicus* distribution, increased precipitation limited its distribution. Therefore, it is reasonable to expect that global warming may extend the suitable conditions for *O. lybicus* and increase its seasonal activity. Also, it may increase damage caused by *O. lybicus* through lowering the effect of limiting factors in both fundamental and realized niches. This issue can be bolstered by replacement of susceptible populations. The effect of global climate change on niche shifts has been reported in many arthropods (Skov and Svenning 2004, Moore and Allard 2008, Porretta et al. 2013).

Management of biological invasions would be more effective when an accurate forecasting model is available. However, any shift in fundamental or realized niche by changing environmental tolerance, evolved the biological novelty or changed abiotic factors may hinder forecasting (Tingley et al. 2014). Therefore, we should increase our knowledge regarding limiting factors in the realized niche, especially in the hot spot areas to prevent any niche shifting and population replacement.

Conclusion

Although the *O. lybicus* as a key pest of date palms, causing serious damage to the quality and quantity of date production, nevertheless the extent of this damage can be drastically diminished by respecting some important management practices. *O. lybicus* is known as a global pest with high genetically diverged populations and subsequently various damaging rates. Therefore, chemical control of the pest is recommended to be restricted just to the hot spots and only when the potential of a severe outbreak is high. In the other cases with less niche habitat suitability and low pest-damaging rate, management of *O. lybicus* should be assigned to the other biotic and abiotic limiting factors, e.g., natural enemies, horticultural practices, and climate limitation agents. These managing approaches besides offshoot transplanting between hot spots and the other habitat niches and among the hot spots themselves especially in where we do not have aggressive populations, can prevent predominantly the *O. lybicus* niche shifting and replacing silent populations by aggressive ones.

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