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Predicted Distribution of Visceral Leishmaniasis Vectors (Diptera: Psychodidae; Phlebotominae) in Iran: A Niche Model Study

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Impacts

- Visceral leishmaniasis (VL) is an important vector-borne disease in Iran, and it is transmitted by sand flies. *Phlebotomus kandelakii* is the main vector, and *Ph. major s.l.* and *Ph. alexandri*, which were suspected.
- This study aimed at predicting the probable niches and distribution of these vectors in Iran using the MaxEnt model.
- The predicted distributions were matched with the disease-endemic areas in the country, while it was found that there were some unaffected areas with potential transmission.

Summary

Visceral leishmaniasis (VL) is an important vector-borne disease in Iran. Till now, *Leishmania infantum* has been detected from five species of sand flies in the country including *Phlebotomus kandelakii*, *Phlebotomus major s.l.*, *Phlebotomus perfiliewi*, *Phlebotomus alexandri* and *Phlebotomus tobbi*. Also, *Phlebotomus keshishiani* was found to be infected with *Leishmania* parasites. This study aimed at predicting the probable niches and distribution of vectors of visceral leishmaniasis in Iran. Data on spatial distribution studies of sand flies were obtained from Iranian database on sand flies. Sample points were included in data from faunistic studies on sand flies conducted during 1995–2013. MaxEnt software was used to predict the appropriate ecological niches for given species, using climatic and topographical data. Distribution maps were prepared and classified in ArcGIS to find main ecological niches of the vectors and hot spots for VL transmission in Iran. *Phlebotomus kandelakii*, *Ph. major s.l.* and *Ph. alexandri* seem to have played a more important role in VL transmission in Iran, so this study focuses on them. Representations of MaxEnt model for probability of distribution of the studied sand flies showed high contribution of climatological and topographical variables to predict the potential distribution of three vector species. Isothermality was found to be an environmental variable with the highest gain when used in isolation for *Ph. kandelakii* and *Ph. major* s.l., while for *Ph. alexandri*, the most effective variable was precipitation of the coldest quarter. The results of this study present the first prediction on distribution of sand fly vectors of VL in Iran. The predicted distributions were matched with the disease-endemic areas in the country, while it was found that there were some unaffected areas with the potential transmission. More comprehensive studies are recommended on the ecology and vector competence of VL vectors in the country.

Introduction

Leishmaniasis in both forms of cutaneous (CL) and visceral (VL) is the main vector-borne disease in Iran, transmitted by different species of phlebotomine sand flies (Nadim et al., 2009). Although CL annually affects more than 20 000 new cases in 18 of 31 provinces of Iran, VL has been reported sporadically. However, about 100–300 new cases of VL are reported annually from the endemic areas of the disease located in north-west and south of Iran (Mohebali, 2013). Alvar et al. (2012) reported 149 cases of VL during 2004–2008 from Iran, and an estimated annual incidence of 300–600 was made as the country was put under the moderate class, where the estimated cases were two- to fourfold more than the reported. The Mediterranean type of VL was reported from Iran with *Leishmania infantum* as agent and canines as reservoir hosts (Mohebali, 2013). The main foci for this disease were located in north-west, Ardabil province; and south, Fars province (Nadim et al., 2009). Till now, *L. infantum* is detected from five species of sand flies in the country including *Phlebotomus kandelakii*, *Phlebotomus major* s.l., *Phlebotomus perfiliewi*, *Phlebotomus alexandri* and *Phlebotomus tobbi* (Sahabi et al., 1992; Rassi et al., 2005, 2009, 2012a,b; Azizi et al., 2006, 2008; Absavaran et al., 2009; Oshaghi et al., 2009; Sanei Dehkordi et al., 2011). Although the *Leishmania* parasite was observed in sand fly dissection from *Phlebotomus keshishiani* in an endemic area for VL in Fars province, it was not identified at the species level yet (Seyedi-Rashti et al., 1995). Among these sand flies, *Ph. kandelakii*, *Ph. perfiliewi* and *Ph. tobbi* were mostly reported from north-west of Iran; *Ph. keshishiani* was more distributed in southern parts, and two other species, that is *Ph. major* s.l. and *Ph. alexandri*, were reported more or less from different parts of the country (Karimi et al., 2014).

A sand fly can be considered as vector of leishmaniasis in a given area if *Leishmania* infection is detected on more than one occasions; the infective form of the parasite observed in anterior midgut of the sand fly; the same parasite has been detected from human and reservoir hosts in the area; there was an ecological association and human tendency; experimental transmission was performed successfully; and finally, the geographical distribution of the vector was the same as the disease (Ready, 2013). Based on these factors, three sand fly species are seem to have many roles in VL transmission in Iran, *Ph. kandelakii* as the main vector in north-west, and *Ph. major* s.l. and *Ph. alexandri* as suspected vectors in south-western foci (Nadim et al., 2009; Maroli et al., 2013).

Phlebotomus kandelakii is mostly collected from the mountainous areas of Iran, although in some places it can be found in the plains. The density of this species is usually low, but sometimes high densities have been observed in human dwellings. In mountainous areas, it is collected

from rock cracks and pits, while in plains, it could be found in fox and dog nests and margins of the streams. This species has more tendencies to humidity and so cannot be collected in warm and dry areas. It has positive tendency to light and is collected in altitudes up to 1400 m above sea level (Rassi and Hanafi-Bojd, 2006). *Phlebotomus major* s.l. is a mountainous species, but it is sometimes collected from the plains. The density of this species is usually low. It is been collected from caves, rock cracks and wild animal nests, in an altitude of up to 2400 m above the sea level (Rassi and Hanafi-Bojd, 2006). In Turkey, this sand fly is collected from 30 to 1565 m above the sea level (Kasap et al., 2013). The environmental condition of collection sites for this species in Sinai area of Egypt was as follows: 423–1634 m above sea level, 20–50% relative humidity, 10–17.5°C minimum temperature and 2.5–27.5°C maximum temperature (Kassem et al., 2012). In Italy, *Ph. neglectus* (one species of *Ph. major* complex) had positive correlation with temperature and was negative with relative humidity. It was collected from sea level up to 1300 m, from both sylvatic and domestic/peridomestic environments (Maroli et al., 2002). *Phlebotomus alexandri* is mostly collected from animal shelters, rocks, pits located in the foothills, caves, and so on. However, it is collected from the rodent burrows in the plains as well. This species has more tendencies to mountainous areas rather than plains. It likes humidity and is collected up to 2250 m above the sea level (Rassi and Hanafi-Bojd, 2006).

It is well known that each species has its specific niche in the ecosystem and so will be affected by change in different factors making that ecosystem (Amirpour Haredasht et al., 2013). Changes in the environment lead to changes in the pattern of vector-borne diseases (Patz et al., 2000). How these changes will have impact on the geographical distribution of the sand fly vector species is the question that should be held accountable for future research. Apart from survey on the seasonal changes of diseases, changes in the global weather will have effect on the disease pattern and therefore should be considered. For example, a research on the relationship between El Nino in 1989 and 1995, and cases of visceral leishmaniasis, showed a significant increase in the disease transmission (Franke et al., 2002). Furthermore, human-made changes such as deforestation caused changes in the pattern of disease transmission in sand fly species inhabiting these regions.

Awareness about associations between vector-borne diseases with change in the environment, and finding the logical connection between them can be useful in planning control interventions (Walsh et al., 1993; Salomon et al., 2008, 2011). Forecasting disease-risk areas allows the allocation of reasonable amount of resources to vector control activities in high-priority areas, thus optimizing cost and effort. However, in this type of spatial analysis, results of

the study will depend on the size of problem and the level of access to information (Davies et al., 2003). Models allow researchers to locate the place of collection for a desired vector, to make predictions about the potential spread of their populations, to predict their distribution range in the case of global warming, and to find the relationships between climatic factors, the temporal and spatial distribution of vectors. According to ecological and environmental changes due to global warming, the distribution patterns of animals, including insects, have been changed in recent years. Therefore, using existing data on distribution of sand fly vectors of visceral leishmaniasis, and extracting their needed ecological characteristics, environmental and climatological data and prediction of their distribution across the country will be possible, because each species has its own specific requirements in the ecological niche modelling and these help us to predict the distribution of species in geographical space.

This study aimed to model and predict the probable niches and distribution of *Ph. kandelakii*, *Ph. major* s.l. and *Ph. alexandri* in Iran, based on the geographical coordinates that were collected during last two decades. Findings of this study will help the health authorities to predict the potential of VL transmission in different parts of the country and to make appropriate decisions in high-risk areas.

Materials and Methods

Study area

Iran is the 18th largest country in the world with an area of 1 648 195 km^2, located in Middle East between latitudes of 25° 3′ and 39° 47′ North, and 44° 5′ and 63° 18′ East. Iran's climate ranges from arid or semi-arid in most parts of the country to subtropics along the Caspian coast and the northern forests. On the northern edge of the country (the Caspian coastal plain), temperatures rarely fall below freezing point and the area remains humid for the rest of the year. Summer temperatures rarely exceed 29°C. Annual precipitation is 680 mm in the eastern part of the plain and more than 1700 mm in the western part. To the west, settlements in the Zagros basin experience lower temperatures, severe winters with below zero average daily temperatures and heavy snowfall. The eastern and central basins are arid, with less than 200 mm of rain, and have occasional deserts. Average summer temperatures exceed 38°C. The coastal plains of the Persian Gulf and Gulf of Oman in southern Iran have mild winters, and very humid and hot summers. The annual precipitation ranges from 135 to 355 mm.

Species data

Data on spatial distribution of the studied sand flies were obtained from the IrSandflyBase, the first Iranian database on sand flies (Karimi et al., 2014). Spatial resolution here was the coordinate of the collection sites. One of the main inclusion criteria in that database was to enter information which was published by experts in the field of sand fly taxonomy. Sample points used for modelling that were included in data from faunistic studies on sand flies were conducted during 1995–2014 (Fig. 1), obtained from IrSandflyBase (Karimi et al., 2014). Two newly published papers that included collection sites of *Ph. alexandri* in south-west of Iran were also used (Kaverizadeh et al., 2013; Jahanifard et al., 2014). The data on these papers were not included in IrSandflyBase. The same inclusion criteria were considered for these publications.

Model variables

Bioclimatic variables and altitude layers were obtained from the WorldClim global climate database (http://www.worldclim.org/current) at a spatial resolution of 1 km^2. These variables have been derived from the long-term (1950–2000) monthly temperature and rainfall values to generate more biologically meaningful variables. The bioclimatic variables represent annual trends, seasonality and extreme or limiting environmental factors (Table 1). Spatial analyst of ArcGIS 9.3 was used to prepare Slope and Aspect (the compass direction that a slope faces) layers from Altitude. Then, layers were changed to ASCII raster using ArcMap 9.3 model builder format for the following analysis in MaxEnt model.

Modelling potential occurrence of sand flies

MaxEnt software ver. 3.3.3 was used to predict the appropriate ecological niches for given species, that is *Ph. major* s.l., *Ph. kandelakii* and *Ph. alexandri* (Phillips et al., 2006). We randomly selected 70% of the all reported occurrence points during the last two decades for each species in order to train the model and then use the remaining 30% to evaluate the model accuracy. Jackknife analysis in the MaxEnt software was used to evaluate the contribution of the environmental variables (Fig. 2). All variables with no contribution (0 values) were excluded from the final analysis (Table 1). To determine the first estimate in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative (Phillips et al., 2006). For the second estimate and for each environmental variable in turn, the values of those variables on training presence and background data were randomly permuted. The model was re-evaluated on the permuted data, and the result dropped in training area under receiver operating curve (=AUC: the probability that a random positive
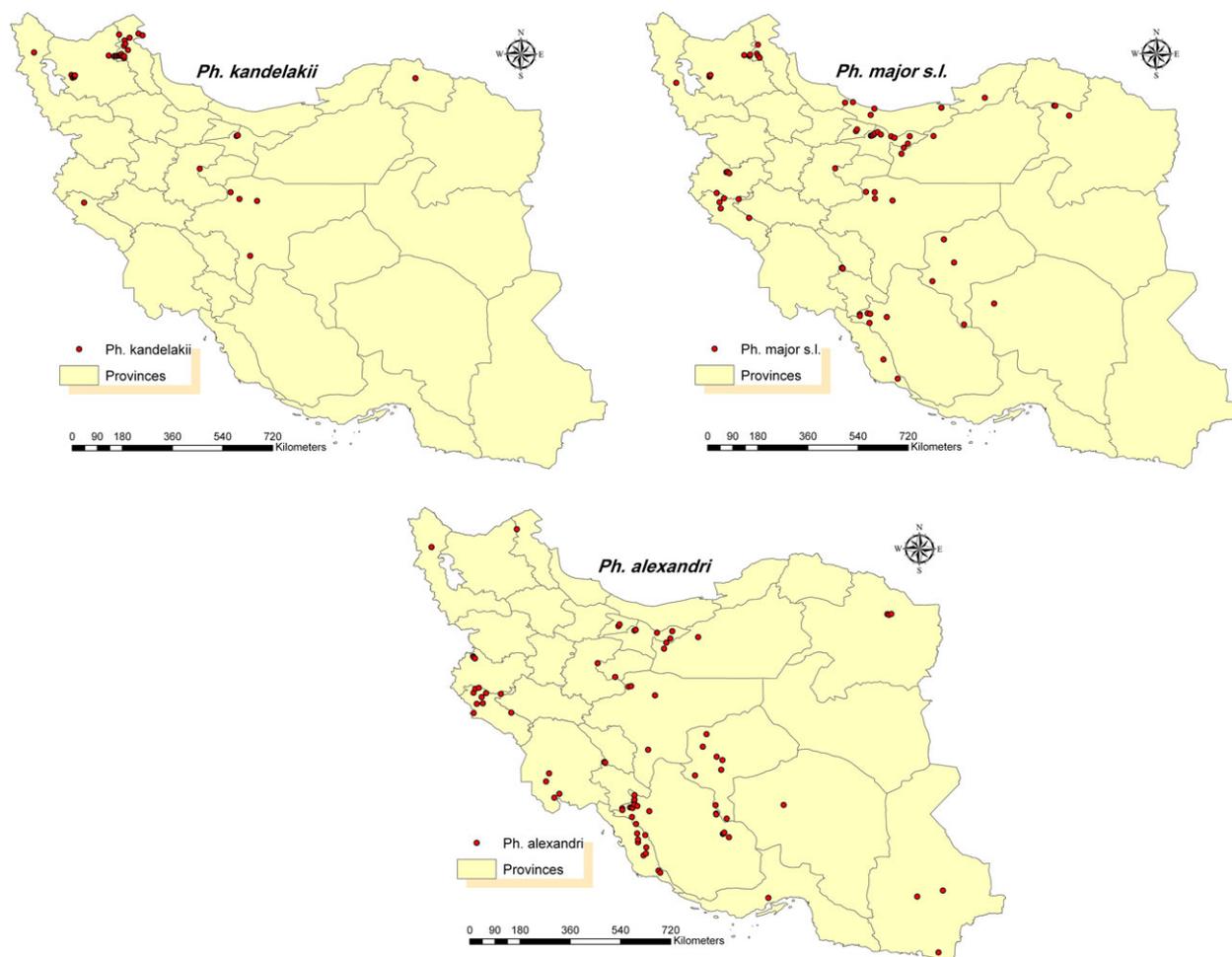
Fig. 1. Sample points of proven/probable vectors of visceral leishmaniasis in Iran used for modelling.

instance and a random negative instance were correctly ordered by the classifier) is shown in the Table 1, normalized to percentages. Distribution maps prepared in MaxEnt as ASCII format were changed to raster and exported in ArcGIS 9.3. These maps were then classified to show the area with 0–20, 21–40, 41–60, 61–80 and 81–100% probability of presence for each sand fly species. The classified map was overlaid with the shapefile of Iran's provinces to find which of them provides more appropriate niches for the given species, and therefore has more potential for VL transmission.

Results

Analysis of variable contributions

Figure 2 shows the results of the jackknife test of variable of importance for three studied species. For *Ph. kandelakii,* the environmental variable with highest gain when used in isolation is isothermality, which therefore appears to have the most useful information by itself. The environmental

variable that decreases gain the most when omitted is precipitation of coldest quarter, which therefore appears to have the most information that is not present in the other variables. Regularized training gain (sum of the likelihood of the data plus a penalty function) is 2.486, training AUC is 0.976, and unregularized training gain is 3.053. The fractional predicted area was 0.392, and the omission rate for test points is 0.0001. At this threshold, test points are significantly better than random ($P < 0.0001$).

About *Ph. major s.l.*, the environmental variable with highest gain when used in isolation is isothermality, which therefore appears to have the most useful information by itself. The environmental variable that decreases gain the most when omitted is also isothermality, which therefore appears to have the most information that is not present in the other variables. Regularized training gain is 0.862, training AUC is 0.889, and unregularized training gain is 1.226. The fractional predicted area is 0.765, and the omission rate for test points is 0.0001. At this threshold, test points are significantly better than random ($P < 0.0001$).

Table 1. Variables used to predict the potential distribution of three main/suspected vectors of visceral leishmaniasis in Iran

Variable	Description	Contribution (%) for species		
		Phlebotomus major s.l.	*Phlebotomus kandelakii*	*Phlebotomus alexandri*
Alt	Altitude from the sea level (m)	1.3	3.9	1.4
Slope	Slope in degrees obtained from Altitude (%)	5.1	3.6	5.5
Aspect	Aspect in degrees obtained from Altitude (Direction)	7	0.2	1.2
BIO1	Annual Mean Temperature (°C)	5	0	1.6
BIO2	Mean Diurnal Range (Mean of monthly (max temp − min temp)) (°C)	0.1	0.4	0.2
BIO3	Isothermality (BIO2/BIO7) ($\times 100$)	49.6	28.9	11.7
BIO4	Temperature Seasonality (standard deviation $\times 100$)	3.7	0	6.5
BIO5	Max Temperature of Warmest Month (°C)	0.3	0.2	4.6
BIO6	Min Temperature of Coldest Month (°C)	2.5	0.9	2
BIO7	Temperature Annual Range (BIO5–BIO6) (°C)	0	2.7	2.2
BIO8	Mean Temperature of Wettest Quarter (°C)	4.8	0	1.7
BIO9	Mean Temperature of Driest Quarter (°C)	0	0	5.6
BIO10	Mean Temperature of Warmest Quarter (°C)	1	0	14
BIO11	Mean Temperature of Coldest Quarter (°C)	0.9	3.5	0.6
BIO12	Annual Precipitation (mm)	8.7	0	10.1
BIO13	Precipitation of Wettest Month (mm)	0.1	0	6.1
BIO14	Precipitation of Driest Month (mm)	0.3	14.4	0
BIO15	Precipitation Seasonality (Coefficient of Variation)	1.2	36.4	1.4
BIO16	Precipitation of Wettest Quarter (mm)	0	0	0.1
BIO17	Precipitation of Driest Quarter (mm)	0	0.2	3.5
BIO18	Precipitation of Warmest Quarter (mm)	6.1	0.5	5.4
BIO19	Precipitation of Coldest Quarter (mm)	2.2	4.2	14.6

Results of the jackknife test of variable of importance for *Ph. alexandri* revealed that the environmental variable with highest gain when used in isolation is precipitation of coldest quarter, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain most when omitted is precipitation of wettest month, which therefore appears to have the most information that is not present in the other variables. Regularized training gain is 0.957, training AUC is 0.914, and unregularized training gain is 1.476. The fractional predicted area is 0.813, and the omission rate for test points is 0.0001. At this threshold, test points are significantly better than random (*P* < 0.0001).

Probable distribution maps

Representations of MaxEnt model classified in ArcGIS for probability of distribution of the studied sand flies are given in Figs 3–5. Orange and red colours show areas with better predictable conditions. As it is presented in Fig. 3, the area with probability of 60% or more for *Ph. kandelakii* was calculated as 17 704 km², mainly in north-west and north. This probability was increased to 130 758 km² for *Ph. major* s.l. (Fig. 4) and 121 108 km² for *Ph. alexandri* (Fig 5). The area with high probability of presence (>80%) for the studied sand

flies was overlaid with elevation, mean temperature and annual precipitation layers (as the main climatic variables affecting the climate of an area) to find the range of these variables for each species. This will help to know more about the ecology of each species, and we think the results will be useful for ecologists in the field of sand flies. Therefore, the range of annual precipitation, mean annual temperature and elevation was calculated as 116–558 mm, 8.5–16.3°C and 418–1637 m for *Ph. kandelakii*; 93–1233 mm, 5.9–24.2°C and −28 to 2410 m for *Ph. major s.l.*; and 91–997 mm, 11.9–25.3 °C and −3 to 2195 m for *Ph. alexandri*, respectively.

Considering these three sand fly species as the most distributed vectors of visceral leishmaniasis in Iran, probability of presence for at least one vector species (Fig. 6a) as well as co-occurrence of three studied species (Fig. 6b) was mapped using raster calculator of spatial analyst in ArcGIS. It means very high potential for VL transmission exists in 20 641 km² area which covers some parts of at least 6 of 31 provinces of Iran. The areas within the provinces in red colour can be considered as hot spots for VL transmission and so they need more survey pertaining to the incidence of the disease among canine reservoirs as well as humans. However, by overlaying the areas with the most vulnerability presence for studied vectors on the layer of VL incidence during 2001–2012, it more or less confirms that more inci-
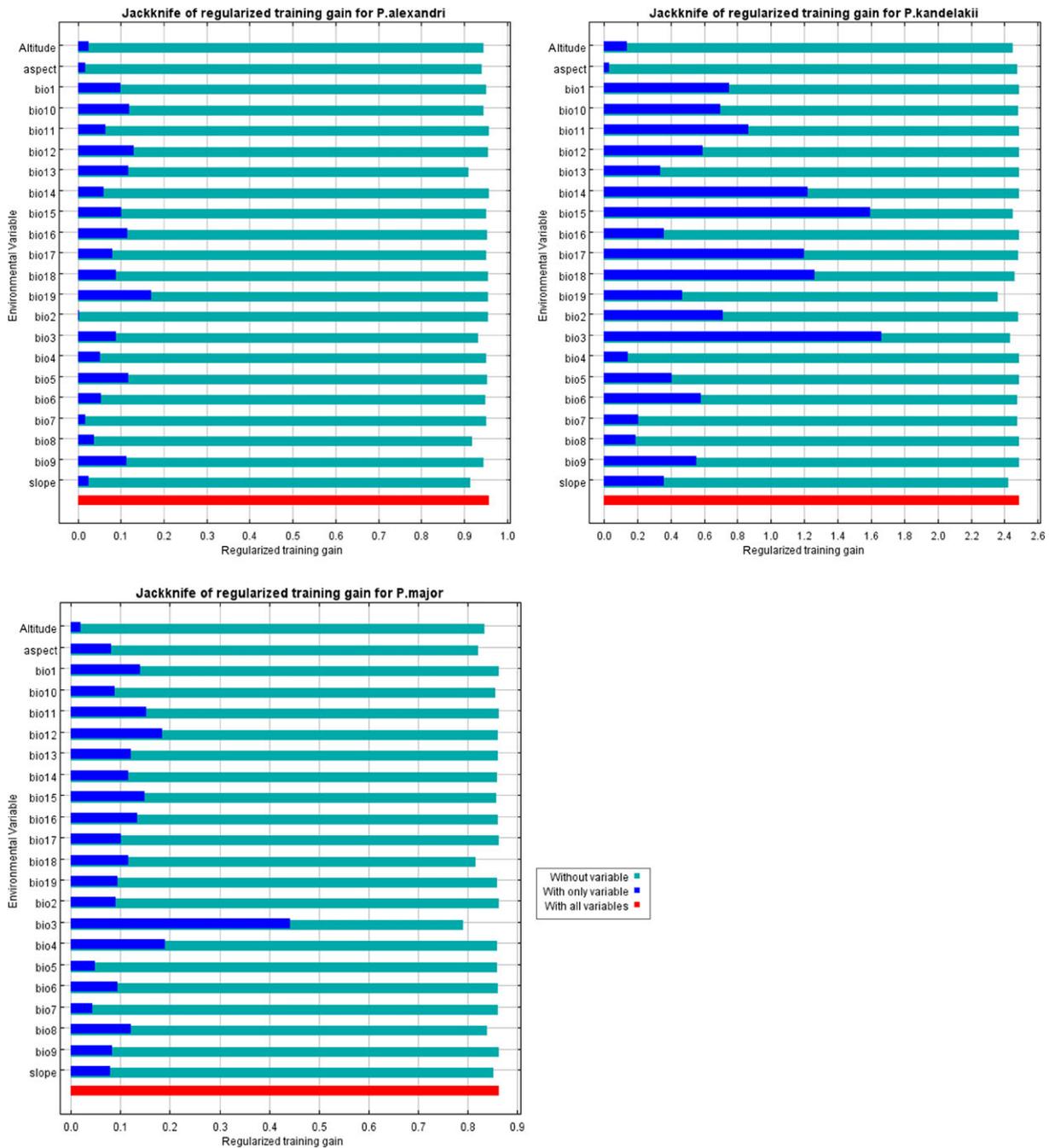
Fig. 2. Jackknife of regularized training gain for *Ph. alexandri, Ph. kandelakii and Ph. major s.l.* in Iran.

dence rates have been reported in the area with higher probability of presence for these vectors (Fig 7).

Discussion

Climatological variables, that is temperature, precipitation and relative humidity, are key factors for developing ecological models, because in the long term, they will have

effect on vegetation and land cover and therefore on the suitability of a habitat for human and animals. Like most of organisms, sand flies seek suitable niches for their breeding and living. Because females need to blood feed for oviposition, they are obliged to live close to mammals. From the perspective of disease transmission, where the reservoir hosts, vector(s) and humans live close enough together, it is possible to establish transmission cycle and, therefore, a
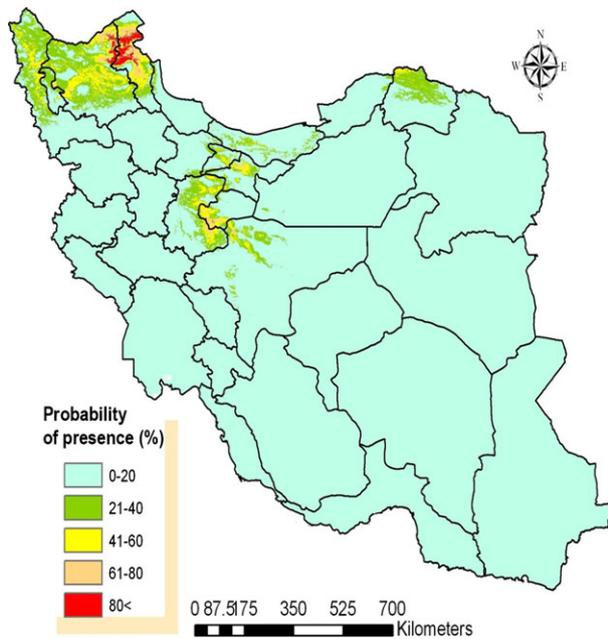
Fig. 3. Representation of MaxEnt model classified in ArcGIS for distribution probability of *Ph. kandelakii* in Iran.

Fig. 5. Representation of MaxEnt model classified in ArcGIS for distribution probability of *Ph. alexandri* in Iran.
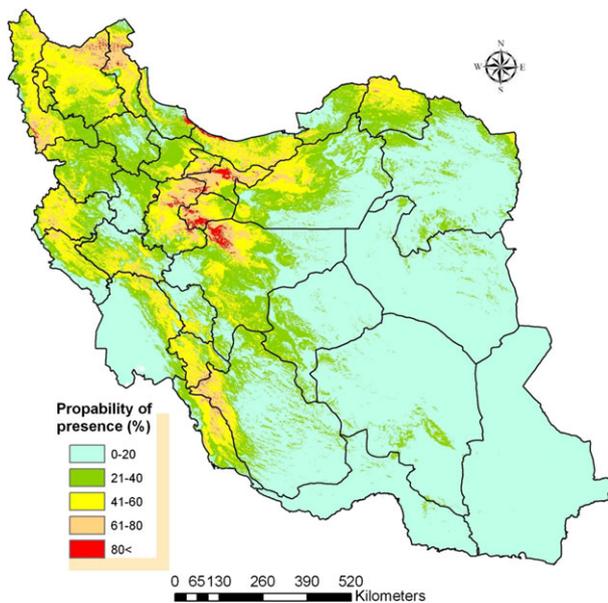

Fig. 4. Representation of MaxEnt model classified in ArcGIS for distribution probability of *Ph. major s.l.* in Iran.

focus of the disease. This pattern of vector distribution has been used for the prediction of transmission risk of leishmaniasis (Elnaiem et al., 1998; Thomson et al., 1999; Gebre-Michael et al., 2004; Samy et al., 2014). Therefore, our study can be useful in the prediction of vulnerability of different parts of Iran for VL transmission and risk.
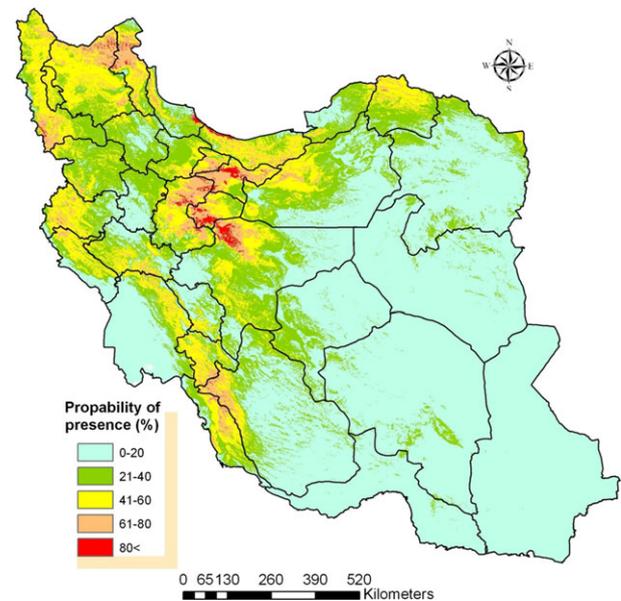
Regarding the vectorial competence of the studied sand flies in their distribution areas across the country, it can be said that *Phlebotomus kandelakii* seems to be the main vector of VL in the northern part of Iran. It is very hydrophilic and moderately thermophilic and easily bites man and large animals in Afghanistan (Lewis, 1978; Killick-Kendrick, 1990). Field studies in the endemic foci of VL in north-western Iran showed the natural infection rate of 0.3–1.1% for this species (Nadim et al., 1992; Rassi et al., 2005). The results of blood meal analysis in this area indicated that *Ph. kandelakii* is strongly anthropophilic with 32.8% containing human blood and 21.2% canine blood (Maleki-Ravasan et al., 2009). Another study in north-eastern part of Iran reported 3.4% specimens infected with *L. infantum* (Rassi et al., 2012a). Two other studied species, *Phlebotomus major* s.l. and *Ph. alexandri*, seem to be vectors of VL in southern foci of the disease in Iran. Promastigote infection rate of *Ph. major* s.l. in this area was reported to be from 3 to 8.3% in Fars province, while *L. infantum* was identified by nested PCR in this sand fly in the area (Sahabi et al., 1992; Azizi et al., 2008). Regarding *Ph. alexandri*, its natural promastigote infection rate was reported as 1.7–4.2%, while *L. infantum* was detected in this sand fly from Fars province (Javadian et al., 1977; Azizi et al., 2006). A survey on synanthropic index of this species in Iran showed its ability to adapt more to urban environments (Jahanifard et al., 2014). Because the species is anthropophilic, it is possible that its feeding preferences would drive the species to more urban environments where humans are more readily available. Therefore, it will increase the risk of transmission.
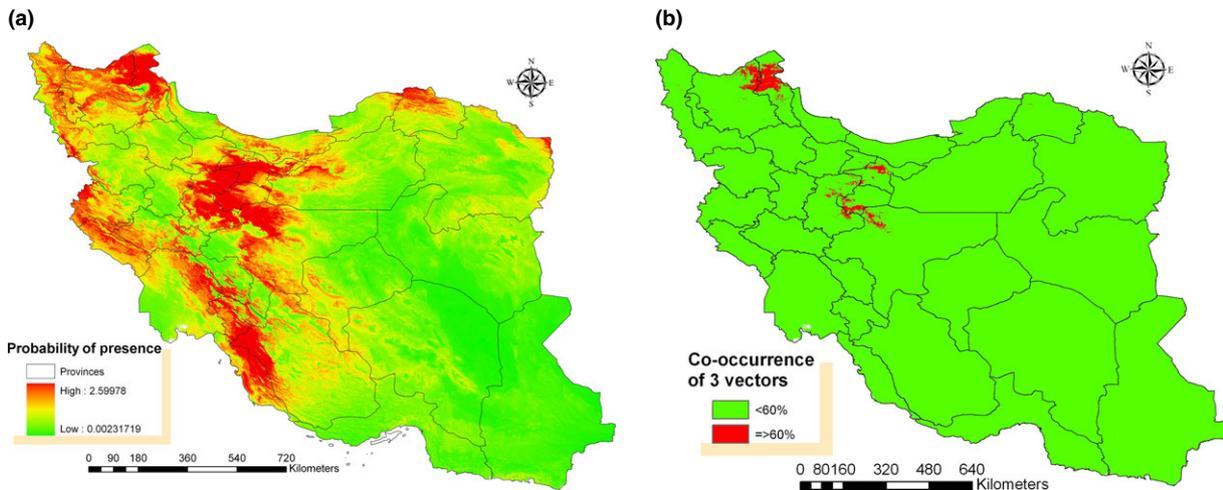
Fig. 6. (a) Probability of presence for *Ph. kandelakii* or *Ph. major* s.l. or *Ph. alexandri*, showing potential areas for VL transmission; (b) Probability of co-occurrence for three studied species.
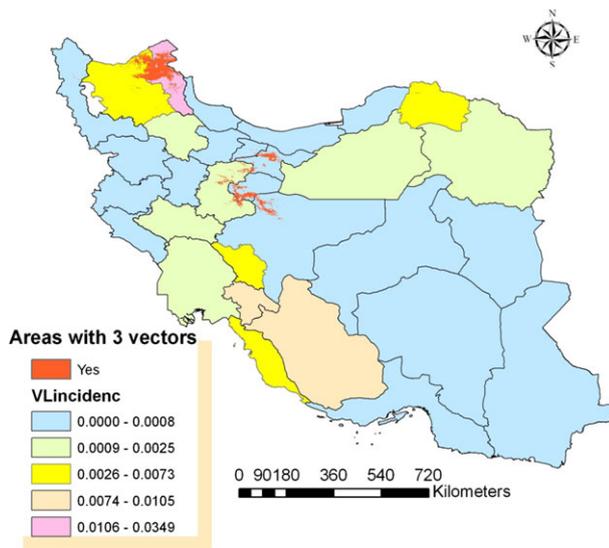

Fig. 7. Co-occurrence of 3 studied vectors overlaid on mean incidence of human VL in Iran, 2001–2012.

By the way, more studies are needed on blood preference of this sand fly and its tendency to blood feeding from canines, the reservoirs of VL in Iran.

Based on the results of modelling, the most extensive probability of occurrence is related to *Ph. major* s.l. followed by *Ph. alexandri* and *Ph. kandelakii*. Co-occurrence of these vectors also covers a surface of 20 641 km² mainly in six provinces: Ardabil, Azarbaijan-e-Sharghi, Tehran, Qom, Markazi and Esfahan. As it can be seen in Figure 7, the main foci of human VL in Iran are located in Ardabil and Azarbaijan-e-Sharghi, where the probability of presence for three vectors is 60% or more. By the way, risk of

transmission in some provinces such as Tehran, Esfahan and Qom is also high and it should be considered in planning for the disease prevention. There were few studies conducted in south-eastern part of Iran, and they did not report *Ph. major* s.l. and *Ph. kandelakii* from that area. Modelling has been performed based on the collection sites for each species (Fig. 1), so the probability of presence is low in this part.

Several environmental factors were found to have affected the presence of sand flies in a given area. They include altitude (Ferreira et al., 2001; Simsek et al., 2007; Ozbel et al., 2011; Kassem et al., 2012), climate (Rispail et al., 2002), soil type (Elnaiem et al., 1998; Thomson et al., 1999), land cover (Colacicco-Mayhugh et al., 2010; Kesari et al., 2013), heat (warming), relative humidity and availability of organic matter (Thomson et al., 1999; Naucke, 2002; Lindgren and Naucke, 2006; Ozbel et al., 2011; Kassem et al., 2012; Kesari et al., 2013), as well as precipitation (Quintana et al., 2013). Land cover was found to have a strong contribution in distribution of sand flies, and the urban area was associated with high probability of these insects (Colacicco-Mayhugh et al., 2010).

Most vectors of *L. infantum* in Iran tend to live in mountainous areas in short summer periods, although *Ph. major* s.l. and *Ph. alexandri* have more extensive distribution across the country (Yaghoobi-Ershadi, 2012; Karimi et al., 2014). Based on the available data used for modelling, *Ph. alexandri* has been reported from 27 m (Sistan va Baluchestan province in south-eastern Iran) to 2581 m (in Yazd province, central Iran) above the sea level, with an average of 1214 m. *Phlebotomus major* s.l. has been collected from 20 m above sea level in Mazandaran province in north, to 2810 m in mountains of Tehran province with an average of 1317 m. These values

were 461–2195 m (both in Ardabil province, north-west of Iran) with an average of 1415 m for *Ph. kandelakii*. Therefore, altitude can be considered as a critical factor to predict the distribution of these sand flies. However, in our study, this factor had a low contribution in model.

Main contributing variables for modelling prediction of the studied sand flies which showed isothermality were the main contributing variables for modelling prediction of *Phlebotomus major s.l.* Area under curve (AUC) in the model for this species was 0.889. In our study, isothermality and precipitation seasonality were the main contributing factors in modelling prediction of *Ph. kandelakii*. Area under curve in the model for this species was 0.976. About *Ph. alexandri*, precipitation of coldest quarter had the most contribution in prediction, and area under curve in the model for this species was 0.914. So, in this study, the model has the best prediction for *Ph. kandelakii* followed by *Ph. alexandri* and *Ph. major* s.l. All predictions have an AUC of more than 0.5; therefore, the model prediction is better than random prediction for all species and can be applied in planning the disease prevention and control. Studies on these sand flies in other countries found that *Phlebotomus alexandri* was more abundant during low-humidity and high-temperature periods in Oman, south of Iran (Roberts, 1994). Species-specific logistic regression modelling in Egypt had identified relative humidity association with distribution of *Ph. alexandri* (Kassem et al., 2012).

Humans are one of the sources of blood for sand flies, especially anthropophilic species. So these insects will drive to urban areas, where their hosts are more readily available. However, the sampling bias towards areas with human leishmaniasis should be considered. The second factor for distribution of sand flies is the vegetation status in a given area, because of the need for their sugar meal. Samples used in our study were collected mainly by sticky paper traps, although in some studies, they used CDC light traps. Sampling method is a critical factor affecting species composition of the sample (Alexander, 2000; Hesam-Mohammadi et al., 2014). On the other hand, sampling place and method, as well as vegetation, can affect the results of niche modelling.

In conclusion, the results of this study present the first prediction on distribution of sand flies in Iran. We found that climatology and topography were variables with high contribution to predict the potential distribution of three vector species. Although evaluating the credibility and accuracy of the data reported in previous years is a controversial issue, this study used the most reliable data for modelling. Due to climate changes in the past few decades, modelling has been performed based on the information in the last two decades. It is performed primarily on the

results of the studies of researchers at Department of Medical Entomology & Vector Control, School of Public Health, Tehran University of Medical Sciences, as the reference centre for Medical Entomology in Iran. This will largely eliminate concerns about the validity of data. Finally, it is recommended that more comprehensive studies be conducted on the ecology of main vectors of VL in the country, for more accurate modelling of their distribution. Such models will be useful for authorities to do costly prediction on the risk of the disease transmission in a given area and to plan for the control programmes in future.

Conflict of interest

The authors have stated no conflict of interest.

Acknowledgements

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