Asian Pacific Journal of Tropical Biomedicine

Journal homepage: www.apjtb.org

doi: 10.4103/2221-1691.242290

Spatial distribution of sand flies (Diptera: Psychodidae; *Larroussius* group), the vectors of visceral leishmaniasis in Northwest of Iran

Eslam Moradi-Asl[1,2], Yavar Rassi[2✉], Davoud Adham[1], Ahmad Ali Hanafi-Bojd[2✉], Abedin Saghafipour[3], Sayena Rafizadeh[4]

[1]*Department of Public Health, School of Public Health, Ardabil University of Medical Sciences, Ardabil, Iran*

[2]*Department of Medical Entomology and Vector Control, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran*

[3]*Department of Public Health, Faculty of Health, Qom University of Medical Sciences, Qom, Iran*

[4]*Ministry of Health, National Institute for Medical Research Development, Tehran, Iran*

ARTICLE INFO

Article history:
Received 8 July 2018
Revision 8 August 2018
Accepted 10 September 2018
Available online 27 September 2018

Keywords:
Larroussius subgenus
Sand fly
Ardabil
Modeling
Iran

ABSTRACT

Objective: To determine spatial distribution of sand flies (Diptera: Psychodidae; *Larroussius* group), the vectors of visceral leishmaniasis in Ardabil province, Northwest of Iran. **Methods:** Sand flies were collected using sticky traps from the 30 selected points in Ardabil province, during May-November 2017. The MaxEnt model in GIS software was used for modeling. **Results:** A total of 2 794 specimens of sand flies were collected, of which 33% were *Larroussius* subgenus sand flies. *Phlebotomus kandelakii* and *Phlebotomus wenyoni* were the highest and lowest collected species respectively. Based on the modeling, four areas in the province were identified with more than 70% probability of the presence of *Larroussius* group vectors which were at risk of visceral leishmaniasis disease transmission. **Conclusions:** The distribution of *Larroussius* subgenus sand flies was observed in all parts of Ardabil. But the northern parts of the province (Germi and Bilesavar counties) as well as central part (Ardabil and Meshkinshahr counties) were of great importance in terms of the presence of *Larroussius* subgenus sand flies and the possibility of transmission of the visceral leishmaniasis.

1. Introduction

Leishmaniasis is a group of systemic diseases that are caused by parasites of the *Leishmania* complex subgenus and transmitted to humans and other mammals by sand flies bites[1,2]. The mortality rate of leishmaniasis is estimated about 51 600 cases in 2010 in the world[3] and it also causes 3.3 million disabilities per year[4]. Leishmaniasis has been reported in 101 countries[5] and over 350 million people are living in at high-risk area of the world[6]. Visceral leishmaniasis (VL) or kala-azar is a severe type of disease that occurs in different parts of the world. Some species of two subgenera of *Phlebotomus* and *Lutzomyia* are the main vectors of diseases in the Old World and New World respectively[7,8]. The annual mortality rate for VL disease is calculated 0.2-0.4 million[6].

✉Corresponding author: Yavar Rassi, Department of Medical Entomology and Vector Control, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran.
E-mail: yrassi@yahoo.com
Ahmad Ali Hanafi-Bojd, Department of Medical Entomology and Vector Control, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran.
E-mail: AAHanafiBojd@tums.ac.ir
Foundation project: This study was funded and supported by the Tehran University of Medical Sciences (Project Number: 31437).

How to cite this article: Moradi-Asl E, Rassi Y, Adham D, Hanafi-Bojd AA, Saghafipour A, Rafizadeh S. Spatial distribution of sand flies (Diptera: Psychodidae; *Larroussius* group), the vectors of visceral leishmaniasis in Northwest of Iran. Asian Pac J Trop Biomed 2018; 8(9): 425-430.

More than 90% of VL disease cases are reported from five countries of Brazil, India, Nepal, Bangladesh and Sudan[9]. In Iran, the disease is sporadically reported from different regions, but the endemic areas have been located in rural parts of the northwest, northeast and southern Iran[10–13]. Annually, 100-300 new cases of VL are reported from Iran, especially in Ardabil province[14] and more than 89% of affected cases were children under 5 years old of age[15]. So far, in Iran, 44 species of the sand flies have been reported and the presence of other 10 species was doubtful[16]. Among them, six species of sand flies in *Larroussius* group and *Paraphlebotomus* subgenera have been identified as the main or probable vectors in the transmission of VL in Iran[13,17–22]. Three species of them including *Phlebotomus major* (*P. major*), *Phlebotomus keshishiani* and *Phlebotomus alexandri* in southern Iran and the rest including *Phlebotomus kandelakii* (*P. kandelakii*), *Phlebotomus perfiliewi* (*P. perfiliewi*) and *Phlebotomus tobbi* (*P. tobbi*) in northwest and northeast of Iran (Ardabil province) are reported as the vectors of the disease. The main aim of this study was to determine the distribution of sand flies in subgenus *Larroussius* as the vectors of VL in different regions of Ardabil province in northwest of Iran and to model their probability of the presence in the province to establish a VL disease surveillance system.

2. Materials and methods

2.1. Study sites

Ardabil province is one of 31 provinces of Iran located on the northwest of the country with a longitude of 38.251 4 and latitude of 48.297 3. The population of province was 1 270 420 people in 2017. This province has 10 counties and has a cold region in the northwest of Plateau with an area of 17 952.5 Sq.km. It is part of the triangular Plateau of Iran in the east of Azerbaijan Plateau, about 2/3 of which has mountainous texture with high altitude and the rest is formed by the flat and low areas. The climate of Ardabil province is largely dependent on four factors of altitude, latitudes, water resources and Migratory Lows. Other factors such as vegetation, industrial and mining agricultural activities affect in small (Figure 1).

2.2. Sand flies collection

Sand flies were collected from 30 areas of 10 counties in the province during May-November 2017. The studied areas were identified and selected based on the prevalence of human cases of VL during the last 15 years. Six urban areas and twenty-four villages were selected and their geographic coordinates and altitude were recorded by GPS (Figure 1). Sand flies were collected using caster oiled papers (60 papers for indoors and outdoors of each area). They were installed before sunset and collected the following morning before sunrise. All collected sand flies were transferred to acetone and then stored in the 70% alcohol. All specimens were mounted a single drop of Puris' medium and were identified using relevant identification keys[23,24].

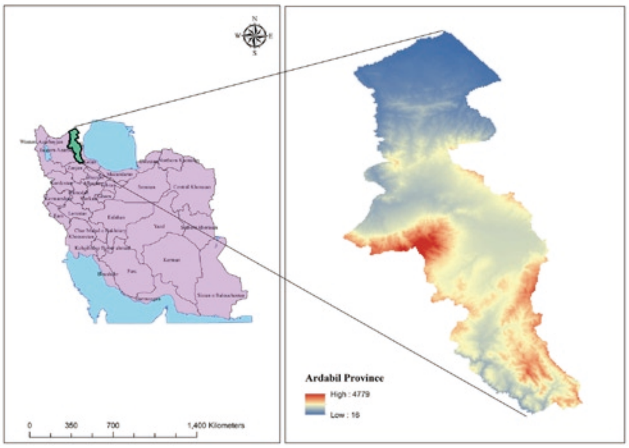

Figure 1. Study area in Ardabil province, Iran 2017.

2.3. Data analysis

Excel and SPSS version 21 were used to analyze the collected data. Poisson's regression analysis was conducted to investigate the relationship between sand fly frequency with average monthly temperature and relative humidity (P<0.05).

2.4. Modeling

The Maxent version 3.3.3 was used to predict the presence of subgenus *Larroussius* sand flies in order to prepare the distribution map at 52 locations (22 locations from previous published studies and 30 locations from the finding of present studies) in Ardabil province northwest of Iran[13,21,25–28]. Jackknife test was used to analyze the relationship between weather variables and distribution of sand flies and the relevant variables were identified with percentages and non-relevant variables were assigned zero. The output of the Maxent model was included in the ArcMap software and the probability of the presence of *Larroussius* subgenus members was divided to 5 categories of 0%-10%, 11%-30%, 31%-50%, 51%-70% and more than 70%. The output map of the ASCII format was converted into the raster format in the GIS software version 10.3.

3. Results

A total of 2 794 sand flies were collected and identified, of which 33.1% belonged to the *Larroussius*, 8.5% *Adlerius*, 20% *Paraphlebotomus*, 23.7% *Phlebotomus*, 0.2% *Synphlebotomus* and 14.5% *Sergentomyia* subgenera. From the *Larroussius* subgenus five species of *P. kandelakii*, *P. perfiliewi transcaucasicus*, *P. tobbi*, *P. major* and *Phlebotomus wenyoni* (*P. wenyoni*) were observed. The most frequency was related to *P. kandelakii* (39.3%) and the least frequency was related to *P. wenyoni* (0.4%) (Table 1). Considering sex, 72% of the sand flies were males and 28% of them were females. The sex ratio for the total of collected sand flies, the *Larroussius* sand flies and the *P. kandelakii* as the dominant species were calculated as 256.83, 258.14 and 185.82, respectively.

Table 1

Sand flies (*Larroussius* subgenus) fauna in the studied area, Northwest of Iran, 2017.

County	Collection site	*P. kandelakii*	*P. tobbi*	*P. perfiliewi*	*P. major*	*P. wenyoni*	Total
Meshkinshahr	Gasabe	34	5	12	12	0	63
	Kangarlu	27	3	6	9	1	46
	Parikhan	55	14	15	30	0	114
	Daryaman	14	3	23	12	0	52
Germi	Shahrak	24	2	24	22	0	72
	Ibishabad	7	2	15	6	0	30
	Rohkandi	7	2	18	3	0	30
Bilehsavar	Injirlu	22	2	20	10	0	54
	Foladlu	7	2	18	2	0	29
	Bodje	2	1	4	1	0	8
Parsabad	Aslanduz	10	2	12	6	0	30
	Iran abad	5	0	6	2	0	13
	Khangah	6	2	8	3	0	19
Khalkhal	Tolash	4	0	4	4	0	12
	Andabil	10	2	18	3	0	33
Sareyn	Sareyn	4	1	4	3	0	12
	Viladarag	7	2	16	1	0	26
	Aldashin	0	0	14	5	0	19
	Talebgeshlagi	30	2	10	9	0	51
Ardabil	Divlag	32	1	5	8	1	47
	Hamlabad	18	2	4	6	0	30
	Garegeshlag	0	0	0	4	0	4
Kowsar	Chalgarod	5	2	5	4	2	18
	Gorgabad	0	1	9	1	0	11
Namin	Namin	21	0	12	6	0	39
	Nanekaran	0	0	2	1	0	3
	Anbaran	0	2	5	3	0	10
	Geynarje	0	4	6	7	0	17
Nir	Borjlu	9	0	0	7	0	16
	Nir	3	0	4	9	0	16
Total		363	59	299	199	4	924

Two main vectors of *P. perfiliewi transcaucasicus* and *P. kandelakii* (*Larroussius* group species) were collected from 93% and 82% of the studied areas. The monthly activity of the *Larroussius* sand flies is started from end of May and is finished in late November with one peak in July (Figure 2).

The results showed that 43% of the sand flies were collected from indoor and the rest from outdoor sites. The highest number of sand flies (15%) was collected from the stables (indoors) and the yards (24.5%) as outdoors places (Table 2).

Using *Chi*-square analysis, the relationship between the species collection in the indoor and outdoor spaces was significant ($P<0.05$). The frequency of all species in indoor areas was less than outdoor sites, except for *P. kandelakii* which is collected with frequency of 59% in indoor sites.

The results of linear regression analysis for each temperature, humidity and rainfall variables indicated that there is a significant relationship between temperature and humidity with monthly activity of sand flies ($P<0.05$), but there is no significant relationship between rainfall and seasonal activity of sand flies ($P>0.05$). The result of the Maxent model showed that the sub-curve surfaces (AUC) for *P. kandelakii* and *Larroussius* group were 0.809 and 0.783, respectively.

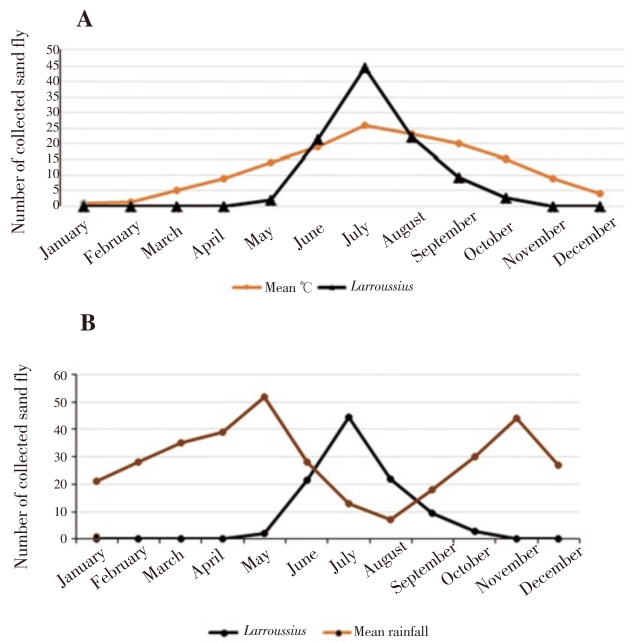

Figure 2. Correlation of seasonal activity of sand flies with temperature (A) and rainfall (B), 2017.

3.1. Jackknife analysis for Larroussius subgenus sand flies

In Figure 3 (Right), the predicted potential locations for the presence of *Larroussius* subgenus sand flies are shown. In the study, the red color revealed the probability of presence of the subgenus *Larroussius* which is more than 70%, and the probability of transmission of the VL in these areas was very high. The results of the jackknife test showed that among the environmental and climate variables, the ground slope, NDVI, slope and Bio-15 (seasonal precipitation) have the greatest effect on the distribution of *Larroussius* subgenus in Ardabil province (Figure 4).

3.2. Jackknife analysis for P. kandelakii (main vector)

P. kandelakii is the main vector in the Northwest of Iran and the

Table 2

Collection of *Larroussius* group sand flies in different sites, Northwest of Iran, 2017.

Larrossius group	Indoor						Outdoor				
	Bedroom	Bathroom	Toilet	Animal shelters	Chicken coops	Warehouse	Yard	Wall	Rock and mountain gap	Ruined places	Fox and rodent nest
P. perfiliewi	14	15	40	21	6	17	62	8	19	34	63
P. tobbi	1	0	2	5	1	1	2	0	22	0	25
P. wenyoni	0	0	0	0	0	0	2	0	0	0	2
P. major	19	0	11	6	12	11	74	4	43	4	15
P. kandelakii	51	13	30	107	6	7	86	12	33	11	7
Total	85	28	83	139	25	36	226	24	117	49	112

province of Ardabil. The probability of presence of this species with more than 70% was determined in three counties of Meshkinshahr, Germi and Ardabil (Figure 3 Left). The most significant climate variables that affected the distribution of the species were NDVI, Bio-15 (Seasonal precipitation), slope, and Bio-7 (annual temperature range) (Figure 5). The relationship between environmental and climate variables was direct which coincides with the peak activity of the sand flies, especially for *Larroussius* sand flies and the NDVI of the region was maximum in June and July. According to seasonal rainfall and temperature, the most frequency of sand flies was observed in July and August when the air temperature was increased and seasonal rainfall decreased (Figure 2).

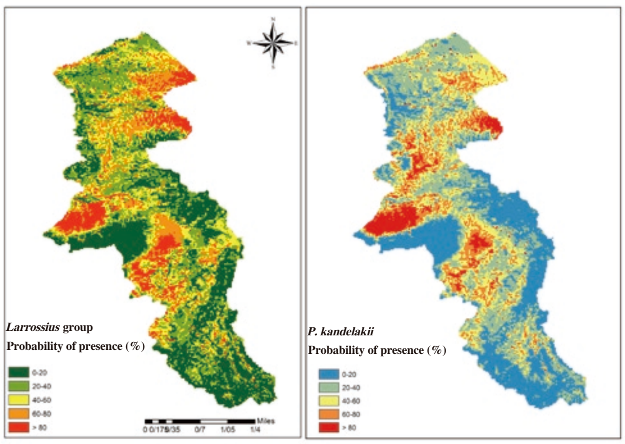

Figure 3. Probability of presence areas for the sand flies vectors of visceral leishmaniasis (*Larrossius* subgenus) in Northwest of Iran, 2017.

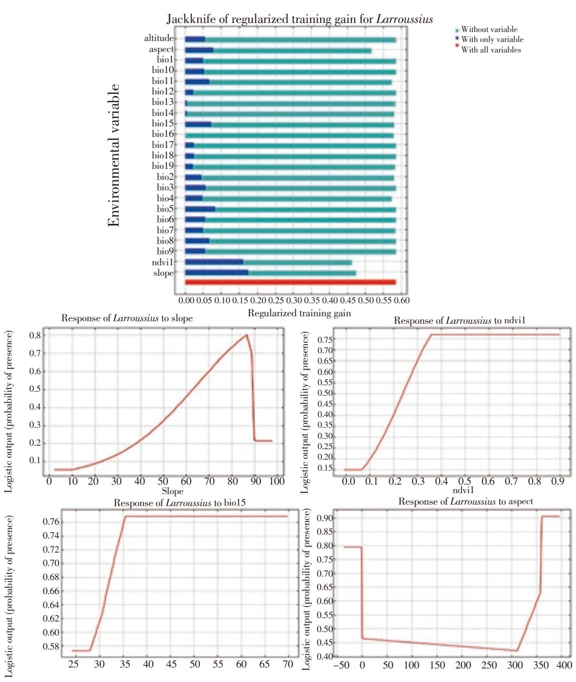

Figure 4. Jackknife test in MaxEnt model for *Larroussius* subgenus sand flies and response to the most influencing factors.

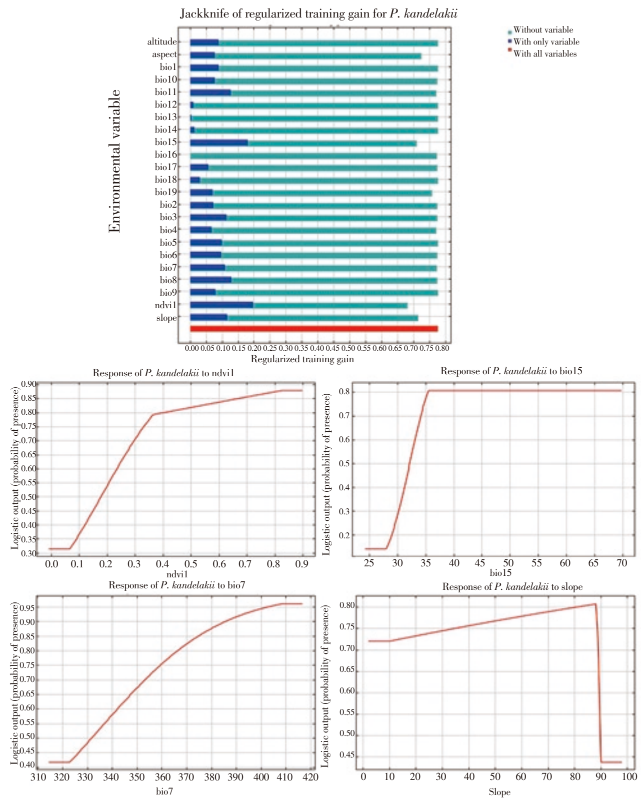

Figure 5. Jackknife test in MaxEnt model for *P. kandelakii* and response to the most influencing factors.

4. Discussion

The main purpose of this study was to determine the spatial distribution of *Larroussius* group sand flies in Ardabil province as one of the main foci of VL in the Iran[18]. The evaluation of distribution pattern of the sand flies is very important in this area because since the year 1949, when the first case of the VL was reported in Iran, by the end of 1997, about 5 244 cases of the VL were reported in Iran with 43.5% of them from Ardabil province[29,30]. In this study, most diversity of subgenus *Larroussius* sand flies including *P. kandelakii*, *P. perfiliewi transcaucasicus*, *P. major*, *P. tobbi*, and *P. wenyoni* was found compared to previous studies[21,26-28]. In the center of Europe, among the vectors of *Leishmania infantum*, five species including *Phlebotomus ariasi*, *Phlebotomus mascittii*, *Phlebotomus perniciosus*, *Phlebotomus neglectus* and *P. perfiliewi* were identified and reported[31]. Our study showed that among the specimens of subgenus *Larroussius*, the two species of *P. kandelakii* and *P. perfiliewi transcaucasicus* were more prevalent in the Ardabil province which was compatible with previous studies[21,26-28]. Also the natural infection of these species with *Leishmania infantum* and *Leishmania donovani* was reported 1%-1.5% from different areas of the Ardabil province which confirmed that they play the main role in transmission of VL to human in the province. According to these studies, the abundance of *P. kandelakii* in the Meshkinshahr and Ardabil and *P. perfiliewi transcaucasicus* in Germi was high, which were in consistent with earlier studies[13,18]. The collection rates of *Larroussius* subgenus sand flies in outdoor and indoor sites were found 57% and 43% respectively, indicating the high abundance of sand flies in outdoor places, which were similar to the results of another study conducted in central Iran[32]. The male sand flies were collected 2.5 times more than the female sand flies, which indicated the higher abundance of males against females. In most studies, the male to female ratio was 3-2 times confirming the same results[33–35]. In this study, the sticky trap technique was used to indicate that males are more attracted to this type of trap while, if the light trap was used, females were mostly absorbed. A study in India reported *Phlebotomus argentipes* was more attracted to light traps[36]. Modeling for one or more of the vectors of diseases helps to determine the potential of the distribution of vectors species in a region, thereby detecting the pattern of distribution of diseases transmitted by vectors[37,38]. Many studies in the world and Iran are done on modeling of CL[38–41]. About vectors of VL, an earlier study in Iran modeled the three important vector species of *P. major*, *Phlebotomus alexandri* and *P. kandelakii*[42]. The results of modeling for subgenus *Larroussius* sand flies in the province of Ardabil for the first time showed that four counties were important in terms of the probability of presence of subgenus *Larroussius* sand flies, two areas in the north part (Germi and Bilehsavar), which are located across the borders of the Republic of Azerbaijan, and two areas (Ardabil and Meshkinshahr) in the center part of that are located to the borders of East Azerbaijan Province. In these four areas, about 64 838 people were at risk of transmitting the VL. In addition, Meshkinshahr has been a tourist destination and the Bilehsavar has a border terminal with the Republic of Azerbaijan, which is visited by a large number of travelers and tourists from these two regions and provinces every month, and they are also at risk in this regard. In this study the most variables that affected the distribution of subgenus *Larroussius* were slope, NDVI, seasonal rainfall and slope direction. In a study conducted in Brazil, NDVI index was the one of the most influential environmental factors on distribution of *Lutzomyia longipalpis*[43]. Hanafi-Bojd *et al.* conducted modeling for three main vectors of VL in Iran and revealed that the important factor was isotermality which had the greatest effect on the distribution for all three species[42]. The results of the study of Camila Gonzalez in North America, which modeled on *Lutzomyia* sand flies, showed that the greatest effect on the distribution of *Lutzomyia* sand flies were the average temperature in the cold and hot months of the year as well as the annual average temperature[44]. In modeling for *Phlebotomus perniciosus* using Maxent, the NDVI had a direct effect on the distribution of this vector in Europe[31], and in another study in Central Europe, the variables of climate, mean temperatures in hot and cold months and annual rainfall were more effective on the vectors of VL[45]. So, climate change and environmental factors have a significant impact on the development of vectors in the world. These changes and their effects on vectors distribution and VL should be regularly monitored. However, the cold weather in the studied area and being mountainous were limitations of present study.

In conclusion, the findings of this study showed that the vectors of VL were dispersed in most parts of Ardabil province and four important foci have been identified in province with more than 70% of the probability of presence of *Larroussius* subgenus sand flies, where the VL could be transmitted in these regions. More comprehensive studies are needed to identify other vectors with novel methods, such as molecular methods which are recommended for next studies.

Conflict of interest statement

We declare no conflict of interest.

Acknowledgments

The authors are grateful to all colleagues at the University of Medical Sciences and staff at the health centers in the all counties in Ardabil Province. This study was funded and supported by the Tehran University of Medical Sciences (Project Number: 31437).

References

[1] Lukeš J, Mauricio IL, Schönian G, Dujardin JC, Soteriadou K, Dedet JP, et al. Evolutionary and geographical history of the *Leishmania donovani* complex with a revision of current taxonomy. *Proc Natl Acad Sci U S A* 2007; **104**(22): 9375-9380.

[2] World Health Organization. *Control of the leishmaniases: Report of a meeting of the WHO Expert Committee on the Control of Leishmaniases*. Geneva: World Health Organization; 2010, p.186.

[3] Lozano R, Naghavi M, Foreman K, Lim S, Shibuya K, Aboyans V, et al. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: A systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012; **380**: 2095-2128.

[4] Murray CJ, Vos T, Lozano R, Naghavi M, Flaxman AD, Michaud C, et al. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: A systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012; **380**: 2197-2223.

[5] Di Muccio T, Scalone A, Bruno A, Marangi M, Grande R, Armignacco O, et al. Correction: Epidemiology of imported leishmaniasis in Italy: Implications for a European endemic country. *PloS One* 2015; **10**: e0134885.

[6] Savoia D. Recent updates and perspectives on leishmaniasis. *J Infect Dev Ctries* 2015; **9**(6): 588-596.

[7] Torres-Guerrero E, Quintanilla-Cedillo MR, Ruiz-Esmenjaud J, Arenas R. Leishmaniasis: A review. *F1000 Res* 2017; **6**: 750.

[8] Elmahallawy E, Sampedro Martinez A, Rodriguez-Granger J, Hoyos-Mallecot Y, Agil A, Navarro Mari J, et al. Diagnosis of leishmaniasis. *J Infect Dev Ctries* 2014; **8**: 961-972.

[9] Souza VA, Cortez LR, Dias RA, Amaku M, Ferreira Neto JS, Kuroda RB, et al. Space-time cluster analysis of American visceral leishmaniasis in Bauru, São Paulo State, Brazil. *Cad Saude Publica* 2012; **28**(10): 1949-1964.

[10]Mohebali M. Epidemiological status of visceral leishmaniasis in Iran: Experiences and review of literature. *J Clinic Experiment Pathol* 2012; **S3**: 003.

[11]Sarkari B, Hatam G, Ghatee M. Epidemiological features of visceral leishmaniasis in Fars Province, southern Iran. *Iran J Public Health* 2012; **41**(4): 94-99.

[12]Oshaghi MA, Maleki Ravasan N, Javadian E, Mohebali M, Hajjaran H, Zare Z, et al. Vector incrimination of sand flies in the most important visceral leishmaniasis focus in Iran. *Am J Trop Med Hyg* 2009; **81**(4): 572-577.

[13]Rassi Y, Sanei Dehkordi AR, Oshaghi MA, Abai MR, Mohtarami F, Enayati AA, et al. First report on natural infection of the *Phlebotomus tobbi* by *Leishmania infantum* in northwestern Iran. *Exp parasitol* 2012; **131**(3): 344-349.

[14]Mohebali M. Visceral leishmaniasis in Iran: Review of the epidemiological and clinical features. *Iran J Parasitol* 2013; **8**(3): 348-358.

[15]Moradi Asl E, Mohebali M, Mohammadi-ghalehbin B, Ganji A, Molaei S, Mehrivar R, et al. Study on changes in epidemiological patterns and parameters of visceral leishmaniasis in patients referred to Health Care Centers of Meshkin Shahr during 2001-2012: (A retrospective study). *J Ardabil Univ Med Sci* 2014; **14**: 63-70.

[16]Kassiri H, Javadian E, Seyedi-Rashti MA. List of Phlebotominae (Diptera: Psychodidae) of Iran. *Bull Soc Pathol Exot* 2000; **93**(2): 129-130.

[17]Rassi Y, Javadian E, Nadim A, Zahraii A, Vatandoost H, Motazedian H, et al. *Phlebotomus* (*Larroussius*) *kandelakii* the principal and proven vector of visceral leishmaniasis in north west of Iran. *Pak J Biol Sci* 2005; **8**: 1802-1806.

[18]Rassi Y, Javadian E, Nadim A, Rafizadeh S, Zahraii A, Azizi K, et al. *Phlebotomus perfiliewi transcaucasicus*, a vector of *Leishmania infantum* in northwestern Iran. *J Med Entomol* 2009; **46**(5): 1094-1098.

[19]Rassi Y, Abai MR, Oshaghi MA, Javadian E, Sanei AR, Rafidzadeh S, et al. First detection of *Leishmania infantum* in *Phlebotomus kandelakii* using molecular methods in north-eastern Islamic Republic of Iran. *East Mediterr Health J* 2012; **18**(4): 387-392.

[20]Yaghoobi-Ershadi M. Phlebotomine sand flies (Diptera: Psychodidae) in Iran and their role on *Leishmania* transmission. *J Arthropod–borne Dis* 2012; **6**(1): 1-17.

[21]Dehkordi AS, Rassi Y, Oshaghi MA, Abai MR, Rafizadeh S, Yaghoobi-Ershadi MR, et al. Molecular detection of *Leishmania infantum* in naturally infected *Phlebotomus perfiliewi transcaucasicus* in Bilesavar district, northwestern Iran. *Iran J Arthropod Borne Dis* 2011; **5**(1): 20-27.

[22]Bahrami A, Rassi Y, Maleki N, Oshaghi MA, Mohebali M, Yagoobi-Ershadi MR, et al. *Leishmania infantum* DNA detection in *Phlebotomus tobbi* in a new northern focus of visceral leishmaniasis in Iran. *Asian Pac J Trop Dis* 2014; **4**(2): 110-114.

[23]Theodor O, Mesghali A. On the phlebotominae of Iran. *J Med Entomol* 1964; **1**: 285-300.

[24]Rassi Y, Hanafi-Bojd AA. *Phlebotomine sand flies, vectors of Leishmaniases: Morphology, biology, ecology, and field and laboratory methods with pictorial key of Iranian sand flies*. Tehran, Iran: Noavaran-Elm Publication; 2006, p. 1-251.

[25]Phillips S. A brief tutorial on Maxent. [Online]. Available from: http://biodiversityinformatics.amnh.org/open_source/maxent/. [Accessed 30 August 2018]

[26]Absavaran A, Rassi Y, Parvizi P, Oshaghi MA, Abaie MR, Rafizadeh S, et al. Identification of sand flies of the subgenus *Larroussius* based on molecular and morphological characters in North Western Iran. *Iran J Arthropod–borne Dis* 2009; **3**(2): 22-35.

[27]Sadeghi H, MoradiAsl E, Mohebali M, Hazrati S, Ainolahzadeh F, Zareiy Z. The effect of bendiocarb poison on different vectors of visceral leishmania in Meshkinshahr city, 2010. *J Ardabil Univ Med Sci* 2012; **12**(2): 140-148.

[28]Ghorbani E, Rassi Y, Abai MR, Akhavan AA. Fauna and monthly activity of sand flies at endemic focus of visceral leishmaniasis in the west territory compared to the east of Meshkinshahr district, Ardebil Province. *SISPH* 2015; **12**(3): 97-109.

[29]Edrissian G, Hafizi A, Afshar A, Soleiman-Zadeh G, Movahed-Danesh AM, Garoussi A. An endemic focus of visceral leishmaniasis in Meshkin-Shahr, east Azerbaijan province, north-west part of Iran and IFA serological survey of the disease in this area. *Bull Soc Pathol Exot Filiales* 1988; **81**(2): 238-248.

[30]Soleimanzadeh G, Edrissian GH, Movahhed-Danesh AM, Nadim A. Epidemiological aspects of kala-azar in Meshkin-Shahr, Iran: Human infection. *Bull World Health Organ* 1993; **71**(6): 759-762.

[31]Fischer D, Moeller P, Thomas SM, Naucke TJ, Beierkuhnlein C. Combining climatic projections and dispersal ability: A method for estimating the responses of sand fly vector species to climate change. *PLoS Negl Trop Dis* 2011; **5**(11): e1407.

[32]Saghafipour A, Vatandoost H, Zahraei-Ramazani AR, Yaghoobi-Ershadi MR, Rassi Y, Shirzadi MR, et al. Spatial distribution of phlebotomine sand fly species (Diptera: Psychodidae) in Qom Province, Central Iran. *J Med Entomol* 2017; **54**(1): 35-43.

[33]Abdel-Dayem MS, Annajar BB, Hanafi HA, Obenauer PJ. The potential distribution of *Phlebotomus papatasi* (Diptera: Psychodidae) in Libya based on ecological niche model. *J Med Entomol* 2012; **49**(3): 739-745.

[34]Almeida PSD, Sciamarelli A, Batista PM, Ferreira AD, Nascimento J, Raizer J, et al. Predicting the geographic distribution of *Lutzomyia longipalpis* (Diptera: Psychodidae) and visceral leishmaniasis in the state of Mato Grosso do Sul, Brazil. *Mem Inst Oswaldo Cruz* 2013; **108**(8): 992-996.

[35]González C, Paz A, Ferro C. Predicted altitudinal shifts and reduced spatial distribution of *Leishmania infantum* vector species under climate change scenarios in Colombia. *Acta Trop* 2014; **129**: 83-90.

[36]Dinesh DS, Das P, Picado A, Davies C, Speybroeck N, Boelaert M, et al. The efficacy of indoor CDC light traps for collecting the sandfly *Phlebotomus argentipes*, vector of *Leishmania donovani*. *J Med Vet Entomol* 2008; **22**: 120-123.

[37]Gurgel-Gonçalves R, Galvao C, Costa J, Peterson AT. Geographic distribution of Chagas disease vectors in Brazil based on ecological niche modeling. *J Trop Med* 2012; **2012**: 1-15.

[38]Sofizadeh A, Rassi Y, Vatandoost H, Hanafi-Bojd AA, Mollalo A, Rafizadeh S, et al. Predicting the distribution of *Phlebotomus papatasi* (Diptera: Psychodidae), the primary vector of zoonotic cutaneous leishmaniasis, in Golestan Province of Iran using ecological niche modeling: Comparison of MaxEnt and GARP Models. *J Med Entomol* 2017; **54**: 312-320.

[39]Abedi-Astaneh F, Akhavan AA, Shirzadi MR, Rassi Y, Yaghoobi-Ershadi MR, Hanafi-Bojd AA, et al. Species diversity of sand flies and ecological niche model of *Phlebotomus papatasi* in central Iran. *Acta Trop* 2015; **149**: 246-253.

[40]Hanafi-Bojd AA, Yaghoobi-Ershadi MR, Haghdoost AA, Akhavan AA, Rassi Y, Karimi A, et al. Modeling the distribution of cutaneous leishmaniasis vectors (Psychodidae: Phlebotominae) in Iran: A potential transmission in disease prone areas. *J Med Entomol* 2015; **52**(4): 557-565.

[41]Ebrahimi S, Bordbar A, Rastaghi ARE, Parvizi P. Spatial distribution of sand fly species (Psychodidae: Phlebtominae), ecological niche, and climatic regionalization in zoonotic foci of cutaneous leishmaniasis, southwest of Iran. *J Vector Ecol* 2016; **41**(1): 103-109.

[42]Hanafi-Bojd AA, Rassi Y, Yaghoobi-Ershadi MR, Haghdoost AA, Akhavan AA, Charrahy Z, et al. Predicted distribution of visceral leishmaniasis vectors (Diptera: Psychodidae; Phlebotominae) in Iran: A niche model study. *Zoonoses Public Health* 2015; **62**: 644-654.

[43]Oliveira EFD, Silva EA, Fernandes CEDS, Paranhos Filho AC, Gamarra RM, Ribeiro AA, et al. Biotic factors and occurrence of *Lutzomyia longipalpis* in endemic area of visceral leishmaniasis, Mato Grosso do Sul, Brazil. *Mem Inst Oswaldo Cruz* 2012; **107**(3): 396-401.

[44]González C, Wang O, Strutz SE, González-Salazar C, Sánchez-Cordero V, Sarkar S. Climate change and risk of leishmaniasis in North America: Predictions from ecological niche models of vector and reservoir species. *PLoS Negl Trop Dis* 2010; **4**: e585.

[45]Fischer D, Thomas SM, Beierkuhnlein C. Modelling climatic suitability and dispersal for disease vectors: The example of a phlebotomine sand fly in Europe. *Procedia Environm Sci* 2011; **7**: 164-169.