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ORIGINAL RESEARCH

Temporal Dynamics of Phlebotomine Sand Flies Population in Response to Ambient Temperature Variation, Bam, Kerman Province of Iran

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Abstract

BACKGROUND Variations in climate condition may have changed the dynamic of zoonotic cutaneous leishmaniasis (ZCL) and its agents such as sand flies and reservoir in the Bam Kerman the dry region of Iran.

OBJECTIVES In this study we intend to examine the seasonal and interannual dynamics of the phlebotomine mosquito as a function of ambient temperature in Bam, Kerman one of the main leshmaniasis prevalence area in Iran.

METHODS The MODIS land surface temperature product (LST; MODIS/Terra LST/E Monthly L3 Global 0.05Deg CMG [MOD11C3]) and land-based climatic data were used as explanatory variables. Monthly caught mosquitoes in Bam, Kerman, were used as a dependent variable. The temporal associations were first investigated by inspection of scatterplots and single-variable regression analysis. A multivariate linear regression model was developed to reveal the association between ambient temperature and the monthly mosquito abundance at a 95% confidence level ($P < 0.05$).

FINDINGS The findings indicated that the monthly variation of 0-10 cm of soil depth temperature is the main driver of phlebotomine mosquito temporal dynamics. The developed multivariate model also indicated that the ambient temperature variation was responsible for >0.80 of temporal dynamics of phlebotomine mosquitos in Bam.

KEY WORDS phlebotomine mosquito, zoonotic cutaneous leishmaniasis (ZCL), ambient temperature, temporal association

INTRODUCTION

Leishmaniases are among the most important emerging and resurging vector-borne diseases, second only to malaria in terms of the number of affected people.[1] Leishmaniases are endemic in 98 countries. It is estimated that 14 million people are infected worldwide with about two million new cases occurring each year.[2] Among all leishmaniases, cutaneous leishmaniasis (CL) is the most common.[3] There are about

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214,000 cases reported each year and the estimated annual CL incidence ranges from 691,000 to 1.2 million cases (90% in Afghanistan, Algeria, Saudi Arabia, Brazil, Peru, Iran and Sudan).[2] Among the various ecological factors associated to the distribution of particular Lutzomyia species in the New World and Phlebotomus species in the Old World, climate seems to be a critical factor[1] a lot of studies have indicated potential changes in the geographical distribution of certain vector sand flies associated to climate variability.[4-9] Temperature significantly influences arthropod developmental times and other life history events such as survivorship; however, there are few studies documenting the impact of temperature on phlebotomine sand fies.[10] Theodor (1936) described thermal limits for Phlebotomus papatasi (Scopoli) (Diptera: Psychodidae),[11] and recently, Erisoz-Kasap and Alten (2005)[12] determined the degree-day requirements and developmental zero for this species.[10] Ambient temperature significantly affects the developmental rates, survival of preimaginal stages, and the longevity of adult phlebotomine sand flies.[10] The temporal and spatial changes in temperature, precipitation and humidity that are expected to occur under different climate change scenarios will affect the biology and ecology of vectors and intermediate hosts and consequently the risk of disease transmission. The risk increases because, although arthropods can regulate their internal temperature by changing their behaviour, they cannot do so physiologically and are thus critically dependent on climate for their survival and development.[11] Ambient temperature significantly affects the digestion, metabolic processes, and developmental times of sand flies,[12] ambient temperature also affects the developmental rates of the immature stages, survival of pre-imaginal stages, and longevity of the adult phlebotomine sand flies.[13-18] The effects of ambient temperature on the growth rate, size and longevity of mosquitoes under laboratory conditions have been the subject of numerous investigations. The strongest effects of climate on the ZCL cycle may happen at the extremities of the optimal activity temperature range, which for the sand-fly are in the vicinity of 15–18 °C for the low and 32–40 °C for the high end.[19] If ambient temperature reaches the upper values of this range, the transmission could cease completely, seriously reducing the cases of ZCL. Around 30–32 °C, the vectorial capacity is observed to increase significantly due to the shortening of the incubation period, despite a decrease in the vector's survival.[20] In addition to the direct influence of temperature on the biology of vectors and parasites, changing precipitation patterns can also have short- and long-term effects on vector habitats. Increased precipitation has the potential to increase the number and quality of breeding sites for vectors such as mosquitoes, ticks and snails, and the density of vegetation, affecting the availability of resting sites. Disease reservoirs in rodents can increase when favorable shelter and food availability lead to population increases, in turn leading to disease outbreaks. Human settlement patterns also influence disease trends.[11] Although sand files have a significant impact on public health, only a few studies[21,22] have been carried out to measure their susceptibility to specified environmental conditions such as ambient temperature consequently, little is known about the effects of external factors such as temperature on their development and longevity. In the present work, we intend to investigate the temporal association between 3 ambiant temperature factors (land surface temperature, soil 0-10 cm depth temperature, and air temperature) and sand fly population abundance in Bam, the leishmaniases endemic region of Iran, Kerman Province of Iran.

METHODS

Study Area. Kerman is the largest province of Iran, with a population of 2.7 million, as can be seen in Figure 1. The province covers an area of 181,714 km^2 and is located in the southeastern part of the country. The province consists of 23 districts, and cutaneous leishmaniasis has historically been present in Bam districts. In recent years the disease has expanded and spread to new foci throughout the province. The climate is extraordinarily variable, which makes it unique, depending on the relief of the land. The climate in north and northwestern areas is fairly moderate and dry, whereas in the south and southeast the weather is warm and humid. The altitude varies between 300 m above sea level in Manujan district to about 2600 m in Baft.

Data Collection. In this study we used 2 types of data, the environmental data, including remotely sensed data and European Centre for Medium-Range Weather Forecasts data, and the data on monthly abundance of mosquito also were used. The environmental data that were used in this study has been presented in Table 1.

The Mosquito Collection. All night landing catches of mosquitoes were made monthly in the village environment for 4 consecutive nights (2 successive nights in each site) from January to December 2012. There were 2 5-hour collection periods

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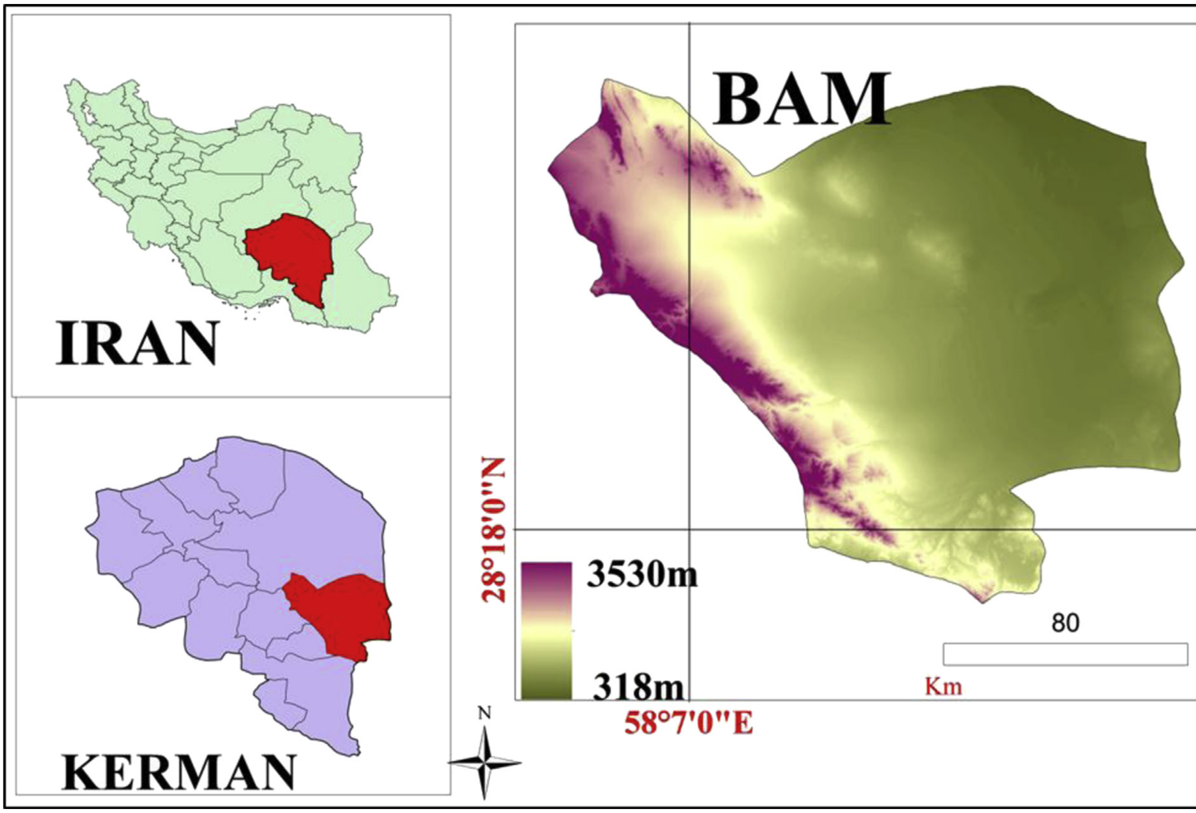

Figure 1. Study area, Bam district in Kerman Province, Iran, one of the main leishmaniasis- prevalent area in Iran.

from 7 PM to 12 AM and 12 AM to 5 AM. Different collectors were used for each period, and collectors changed positions each night to prevent any bias. Mosquitoes were aspirated as they landed on 1 exposed leg of the collector and placed in unwaxed screened 0.5 L ice cream cartons modified as cages.

Statistical Analysis. We examined the temporal association between ambient temperature and monthly phlebotomine vectors abundance using Pearson product-moment correlation coefficient, which measures the direction and strength of association between variables. A 0.95 confidence level ($P < 0.05$) was considered to determine the significance of correlation coefficients. The relationship between monthly caught phlebotomine vectors as independent variable and each thermal explanatory variable was first investigated by inspection of scatter plots and by single-variable regression analysis.

Table 1. Ambient Temperature Indicator Was Used to Evaluate the Association Between Temporal Dynamics of Phlebotomine Sand Flies Population and Ambient Temperature

Level	Data Type	Product	Time	Description	Duration	Format	Source
Land surface temperature	Remotely sensed data	MOD11C3	Daytime Nighttime	Monthly average	January 1, 2005 to December 31, 2012	.HDF	MODIS website
0-10 cm depth soil temperature	ECMWF	Monthly mean of daily mean	12Z UTC (3:30 PM, IR)	Monthly average	January 1, 2005 to December 31, 2012	.NC	http://www.ecmwf.int/
2 m above land Surface air temperature	ECMWF	Monthly mean of daily mean	3:30 PM IR	Monthly average	January 1, 2005 to December 31, 2012	.NC	http://www.ecmwf.int/

ECMWF, European Centre for Medium-Range Weather Forecasts; IR, Iran; UTC, universal time controlled.

Table 2. Monthly Abundance of Caught Mosquitoes in 2 Districts of Bam City (Fakhrabad and Mahdab) From April to December 2012

	Absolute Frequency		Relative Frequency	
	Phlebotomus sergenti	*Phlebotomus papatasi*	*Phlebotomus sergenti*	*Phlebotomus papatasi*
April	41	4	0.028	0.031
May	59	21	0.04	0.046
June	167	52	0.112	0.113
July	431	142	0.29	0.338
August	131	31	0.088	0.068
September	382	99	0.257	0.216
October	182	41	0.122	0.089
November	82	14	0.055	0.031
December	11	6	0.007	0.013
	1486	420		

Finally a multivariate regressions model was developed to determine the association between environmental variables and the occurrence of anopheles with a 0.95 confidence level ($P < 0.05$).

RESULTS

The monthly abundance of caught mosquitoes from April 2012 to December 2012 is mentioned in Table 2. As can be seen in this table, the majority of caught mosquito were *Phlebotomus sergenti.* According to Table 2, 0.22 of mosquitoes were *Ph papatasi* and 0.78 were *Ph sergenti.* As can be seen in this table, the greatest abundance of both species of sand flies occurred in July; 29% of *Ph sergenti* and 33% of *Ph papatasi* abundance occurred in July. In December the relative frequency of caught phlebotomine mosquito for *Ph sergenti* and *Ph papatasi* were 0.25 and 0.21, respectively. In September, a significant decline was observed in the abundance of caught mosquitoes, so that despite the high temperature in this month, less than 10% of mosquito abundance for each species was observed.

As seen in Figure 2 main peaks were observed in the mosquito population in July and September. In August, the mosquito population fell despite the high environmental temperature. We found that 0.54 of the total abundance of caught mosquitoes were in July and September; 0.46 of them were distributed in the other months of the year.

The temporal association among ambient temperature and monthly abundance of caught mosquito is presented in Table 3. As can be seen in this table, 3 ambient temperature factors—namely, air temperature at 2 m high, daytime land surface temperature, and nighttime land surface temperature, and also 0-10 cm depth soil

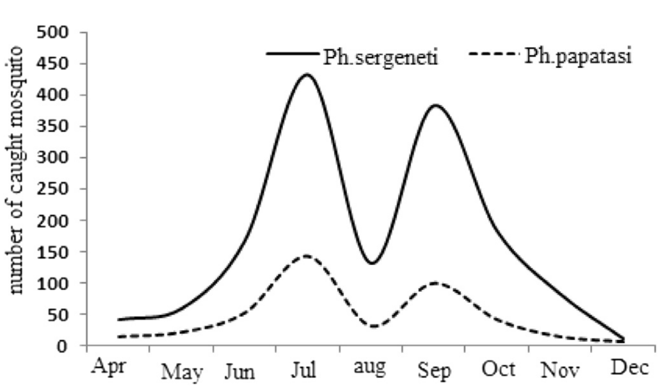

Figure 2. Monthly abundance of caught mosquitoes (2 species, *Phlebotomus sergenti* and *Phlebotomus papatasi*) in Bam.

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Table 3. Correlation Matrix for the Monthly Abundance of Caught Mosquitoes and Thermal Components of the Environment

Temporal Correlation	*Phlebotomus sergenti*	Significance	*Phlebotomus papatasi*	Significance
Air temperature at 2 m high	0.62	39×10^{-5}	0.64	21×10^{-5}
DLST	0.56	45×10^{-4}	0.64	20×10^{-5}
NLST	0.48	42×10^{-5}	0.50	31×10^{-5}
DLST-NLST	−0.11	0.29	−0.18	0.19
0-10 cm depth soil temperature at 00:00 UTC	0.71	12×10^{-5}	0.79	1×10^{-4}

DLST, daytime land surface temperature; NLST, nighttime land surface temperature; UTC, universal time coordinated.

temperature—were positively correlated with monthly abundance of caught mosquitos. But the average monthly difference in daytime and nighttime temperature reveals a reverse association with phlebotomine mosquito abundance.

In Figure 3, in order to illustrate the monthly association among environmental thermal factors and mosquito abundance, we standardized all variables according to normal distribution function (mean and standard deviation). Figure 3 indicated that in all months except August, after the increase of ambient temperature, the abundance of caught mosquito increased, and with a decrease in ambient temperature the mosquito abundance declined. In August, which is the hottest month of year in Bam, increased ambient temperature is concurrent with a significant decrease in relative humidity and near surface soil moisture, which may have led decreases in mosquito abundance.

In Figure 4 the relationship between the abundance of caught mosquitoes and the day-night temperature difference is presented. As can be seen in the figure, the highest day-night thermal variation was in August and November, which led to significant reductions in the abundance of the mosquito population. In August the temperature difference between day and night (at 3:30 AM and 3:30 PM) according to the MOD11C3 product, reached more than 23°C. However, in July and September this difference was less than 15°C, so it is possible that this huge daily thermal variation is one of the factors that led to significant reductions in phlebotomine mosquitos in August and November.

In the Table 4 the scatterplot investigation has been used to analysis the association among mosquito abundance and each thermal factor of ambient temperature. According to the single-variable regression model for each of the environment thermal variables, temperature in 0-10 cm depth soil provided the highest coefficient of determination (R^2) for both species of mosquito. Air temperature with coefficient of 39% (for *Ph sergenti*) and 45% (for *Ph papatasi*) is in second place, but night temperature had the lowest level of the coefficient of determination for both species.

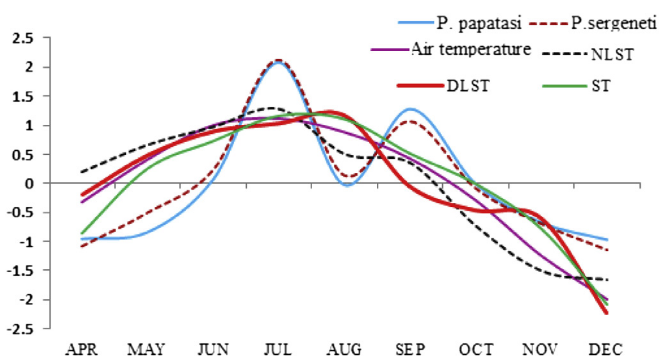


Figure 3. Monthly distribution of caught phlebotomine mosquitos and ambient temperature factors (all value has been standardized according to normal distribution function). DLST, daytime land surface temperature; NLST, nighttime land surface temperature; ST, surface temperature.

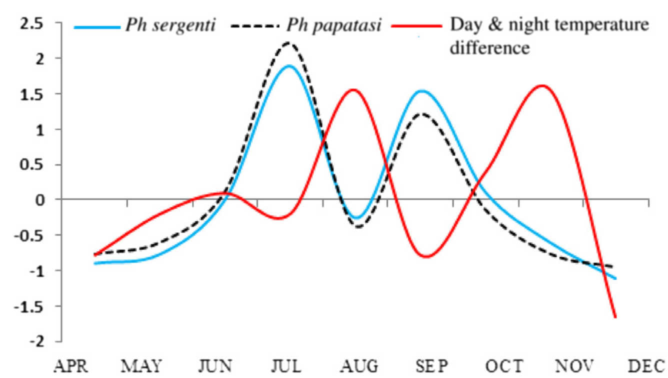


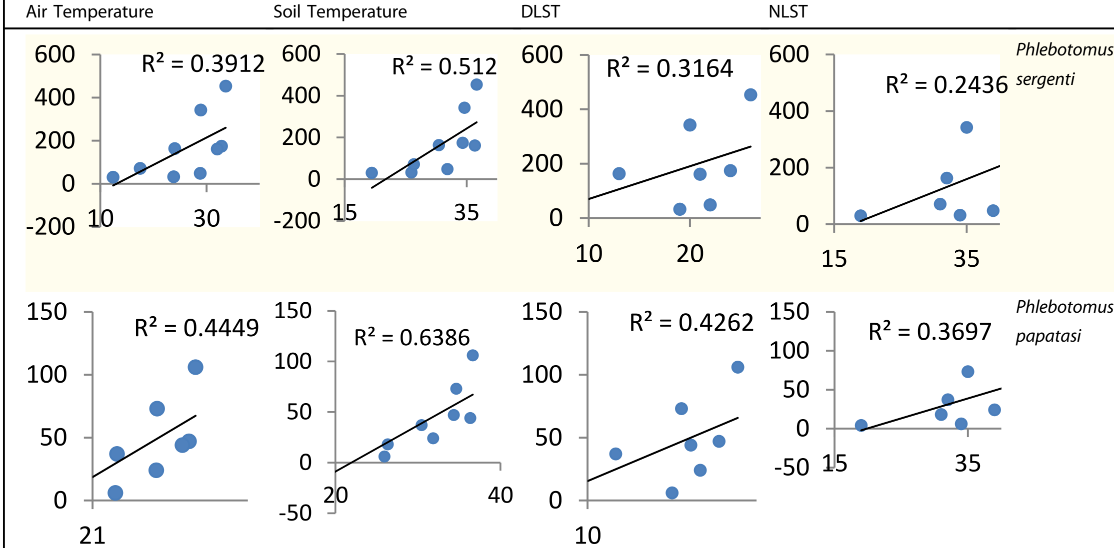
Figure 4. Average daily thermal variations and monthly abundance of mosquito (all value has been standardized according to normal distribution function). P. papatasi, *Phlebotomus papatasi;* P. sergeneti, *Phlebotomus sergenti*.

The correlation matrix reveals a significant positive association among the ambient temperature factors and monthly mosquito abundance. This powerful association enabled us to develop a multivariate regression model to predict the monthly abundance of mosquitos according the ambient temperature factors. In Table 5 we presented 2 developed multivariate regression models to predicting the monthly abundance of phlebotomine mosquitos. As can be seen in this table, soil depth temperature and air temperature have the highest influence on monthly variations of mosquito's population. The daily land surface temperature, as the standardized coefficients indicated, has the lowest level of influence on the mosquito's monthly dynamic. The 2 multivariate regression models indicated that the ambient temperature could explain the 0.82 and 0.88 of temporal variance of population abundance of *Ph sergenti* and *Ph papatasi*, respectively.

In Figure 5 we used scatterplot investigation to compare the caught mosquito versus predicted

Table 4. Scatterplot Inspection of Caught Sand Flies and Each Ambient Temperature Index

Air Temperature	Soil Temperature	DLST	NLST



DLST, daytime land surface temperature; NLST, nighttime land surface temperature.

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Table 5. The 2 Developed Multivariate Regression Models to Estimate Population Abundance of *Phlebotomus sergenti* and *Phlebotomus papatasi* Based on Ambient Temperature

R Adjusted	R^2	Standardized Coefficients (ABS) * β	Unstandardized Coefficients B	Model	
0.64	0.83	—	−732.452	Intercept	*Ph sergenti*
		3.842	−77.7153	Air	
		2.388	51.23083	NLST	
		1.567	−29.4128	DLST	
		3.845	99.8894	Tsoil	
0.77	0.88	—	−178.971	Intercept	*Ph papatasi*
		3.987	−18.1076	Air	
		2.411	11.61371	NLST	
		1.287	−5.42465	DLST	
		3.794	22.13158	Tsoil	

ABS, absolute value; B, coefficient; DLST, daytime land surface temperature; NLST, nighttime land surface temperature; Tsoil, soil temperature at 0-10 cm depth.

mosquito by regression models. According to the proposed models, ambient temperature factors have explained 0.83 and 0.88 of the temporal variance of the populations of *Ph sergenti* and *Ph papatasi* mosquitos, respectively.

CONCLUSIONS

In this study we intended to reveal the thermal sensitivity of monthly dynamics of phlebotomine mosquito population in the Bam district of Kerman Province, Iran. The correlation matrix and scatterplot investigation indicated that there is a significant positive association among ambient temperature factors and monthly dynamics of the phlebotomine mosquito population. The ambient temperature in all months except August lead to increases in the mosquito population. In August, which is the warmest month in Bam, an inverse association between the ambient temperature factors and mosquito abundance was observed. The 2 multivariate regression models that were developed to predict the monthly abundance of mosquito according ambient temperature indicated that the ambient temperature variation was responsible for more than 0.8 of the temporal dynamics of phlebotomine mosquitos.

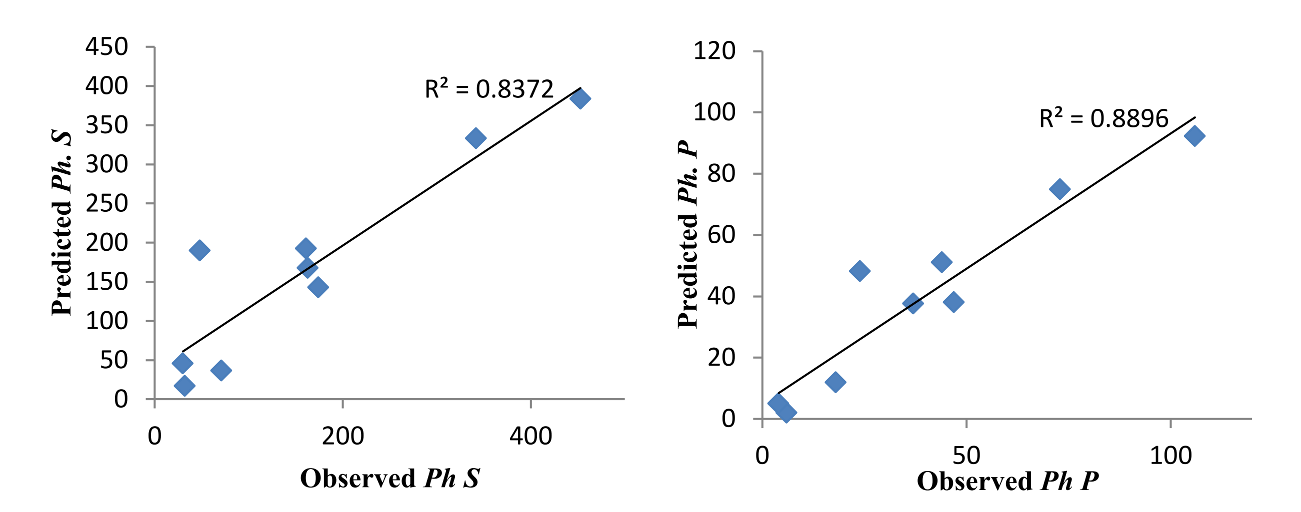

Figure 5. Scatter plot investigation of caught mosquito against predicted mosquito abundance. *Ph P, Phlebotomus papatasi; Ph S, Phlebotomus sergenti.*

REFERENCES

1. Cardenas R, Sandoval CM, Rodríguez-Morales AJ, Franco-Paredes C. Impact of climate variability in the occurrence of leishmaniasis in northeastern Colombia. Am J Trop Med Hyg 2006;75(2):273–7.
2. World Health Organization. World malaria report 2014. Geneva, Switzerland: WHO; 2014.
3. Sutherst RW. Global change and human vulnerability to vector-borne diseases. Clin Microbiol Rev 2004;17:136–73.
4. Cross ER, Hyams KC. The potential effect of global warming on the geographic and seasonal distribution of Phlebotomus papatasi in southwest Asia. Environ Health Perspect 1996;104:724–7.
5. Cross ER, Newcomb WW, Tucker CJ. Use of weather data and remote sensing to predict the geographic and seasonal distribution of Phlebotomus papatasi in southwest Asia. Am J Trop Med Hyg 1996;54:530–6.
6. Kuhn KG. Global warming and leishmaniasis in Italy. Bull Trop Med Int Health 1999;7:1–2.
7. Kovats RS, Campbell-Lendrum DH, McMichael AJ, Woodward A, Cox JS. Early effects of climate change: Do they include changes in vector-borne disease? Philos Trans R Soc Lond B Biol Sci 2001;356:1057–68.
8. Kovats RS, Campbell-Lendrum DH, McMichael AJ, Woodward A, Cox JS. Early effects of climate change: Do they include changes in vector-borne disease? Philos Trans R Soc Lond B Biol Sci 2001;356:1057–68.
9. Alexander B, Ferro C, Young DG, Morales A, Tesh RB. Ecology of phlebotomine sand flies (Diptera: Psychodidae) in a focus of Leishmania (Viannia) braziliensis in northeastern Colombia. Mem Inst Oswaldo Cruz 1992;87:387–95.
10. Alexander B, Agudelo LA, Navarro F, et al. Phlebotomine sandflies and leishmaniasis risks in Colombian coffee plantations under two systems of cultivation. Med Vet Entomol 2001;15:364–73.
11. Kasap OE, Alten B. Laboratory estimation of degree-day developmental requirements of Phlebotomus papatasi (Diptera: Psychodidae). J Vector Ecol 2005 Dec;30(2):328–33.
12. Githeko AK, Lindsay SW, Confalonieri UE, Patz JA. Climate change and vector-borne diseases: a regional analysis. Bulletin of the World Health Organization 2000;78(9).
13. McMichael AJ, Campbell-Lendrum DH, Corvalan CF, Ebi KL, Scheraga JD, Woodwards A, eds. Climate change and human health. Geneva: WHO, WMO, and UNEP; 2003.
14. Benkova I1, Volf P. Effect of temperature on metabolism of Phlebotomus papatasi (Diptera: Psychodidae). J Med Entomol 2007 Jan;44(1):150–4.
15. Rueda LM, et al. Temperature-dependent development and survival rates of Culex quinquefasciatus and Aedes aegypti (Diptera: Culicidae). Journal of Medical Entomology 1990;27:892–8.
16. Gillies MT. The duration of the gonotrophic cycle in Anopheles gambiae and An. funestus with a note on the efficiency of hand catching. East African Medical Journal 1953;30:129–35.
17. Turell MJ. Effects of environmental temperature on the vector competence of Aedes fowleri for Rift Valley fever virus. Research in Virology 1989;140:147–54.
18. Carter TR, Hulme M. Interim characterizations of regional climate and related changes up to 2100 associated with the provisional SRES emissions scenarios: guidance for lead authors of the IPCC Working Group II Third Assessment Report. Washington, DC: IPCC Working Group II Technical Support Unit; 1999 (unpublished document).
19. Watts DM, et al. Effect of temperature on the vector efficiency of Aedes aegypti for dengue 2 virus. American Journal of Tropical Medicine and Hygiene 1987;36:143–52.
20. Lindsay SW, Birley MH. Climate change and malaria transmission. Annals of Tropical Medicine and Parasitology 1996;90:573–88.
21. Manuchehr Farajzadeh, Mansour Halimi , Yousef Ghavidel, Mahdi Delavari. Spatiotemporal Anopheles Population Dynamics, Response to Climatic Conditions: The Case of Chabahar, South Baluchistan, Iran, annals of global health, 2015;81(5): 694–704.
22. Mansour Halimi, Manuchehr Farajzadeh, Mahdi Delavari, Mohsen Arbabi. Developing a climate-based risk map of fascioliasis outbreaks in Iran, Journal of infection and public health, 2015;8(5):481–486.