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Influence of increasing temperature on the scorpion sting incidence by climatic regions

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ABSTRACT: Scorpion stings are a major public health concern representing a frequent cause of intoxication in many countries. The present study aims to examine the impact of climate variability in different climatic regions of the state of Morelos in Mexico on the incidence of scorpion stings. An ecological study was conducted using a retrospective time-series analysis. Weekly reported scorpion sting cases from the Unique System of Information for Epidemiological Surveillance (SUIVE) and daily temperature and precipitation from the National Meteorological Service were obtained from 1999 to 2007. The geographical region of study was divided according three climatic conditions into Hot region (HR), Warm region (WR) and Cold region (CR). Generalized Linear Models were used to estimate the percent change [95% confidence intervals (CI)] of scorpion sting cases associated to an increase of 1 °C of temperature and 1 cm of precipitation in each climatic region. During the period of study there were 281 076 scorpion sting cases reported in the State of Morelos, Mexico. Positive correlations among temperature and scorpion sting cases were found ($R = 0.59$ and 0.70 in the HR and WR, respectively). Regions with the hottest temperatures had the greatest effect, showing a 9.8% (CI 95%: 8.30–11.30) increase in scorpion sting cases per 1 °C increased in temperature. Increase in minimum and maximum temperatures have a delayed effect on scorpion stings cases and these may vary by climatic region.

KEY WORDS temperature; scorpion sting incidence; climate variability

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1. Introduction

Scorpion stings are a major public health concern worldwide. This problem is mainly found in North and South Africa, Sahelian Africa, Near-East and Middle-East, Asia, Mexico, Amazonian Basin and South America. All these regions combined account for 1.19 million stings annually (Chippaux and Goyffon, 2008). There are over 1500 scorpion species in the world (Prendini and Wheeler, 2005), but only 30 of these are considered dangerous for humans (Chippaux and Goyffon, 2008). In Mexico there are 170 different scorpion species, out of these 11 are dangerous to humans (Dehesa-Dávila and Possani, 1994; Beutelspacher, 2000; Fet *et al.*, 2000). The most toxic species found in this country belongs to the genus *Centruroides* family and some examples are *Centruroides noxius*, *Centruroides suffuses*, *Centruroides limpidus limpidus*, *Centruroides limpidus tecomanus* and *Centruroides elegans*. These can be found all over the country and they are responsible for the highest mortality rates (Celis *et al.*, 2007). Mexico reports approximately an annual incidence of 250 000 scorpion stings (Celis *et al.*, 2007; Chippaux and Goyffon, 2008) with a rate of 225 cases per 100 000 inhabitants in 2015 (INEGI, 2016).

Moreover, scorpion sting morbidity rates are not equally distributed among all Mexican states. It has been suggested that higher stings occur in warmest and dry regions with dangerous scorpion species, however, differences of scorpion stings by region still remain unclear (Gómez *et al.*, 2002). According to the National Center of Prevention Programs and Disease Control (Centro Nacional de Programas Preventivos y Control de Enfermedades, CENAPRECE by its acronym in Spanish) in Mexico, during 2006 and 2012, an average of 284 932 annual cases were registered mainly in coastal entities of the Pacific and other entities in the center of the country like Morelos. The populations with the highest risk are rural and marginal urban areas located in endemic entities (CENAPRECE, 2014).

The state of Morelos ranks among the first places of scorpion sting incidence rates in Mexico, with an average of 1778 cases per 100 000 inhabitants. This makes scorpion stings the fifth mortality cause in the state (Secretaría de Salud, 2002, 2003, 2004, 2005, 2006, 2007, 2008a, 2009, 2010), probably due to the presence of *C. limpidus limpidus* in 60% of the region in Morelos

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(Calderon-Aranda *et al.*, 1996; Santibañez-López *et al.*, 2011).

Surface activity of scorpions depends on biotic and abiotic factors. The most relevant abiotic factors for scorpion activity are pluvial precipitation and surface ambient temperature. The combination of temperature decrease and precipitation result in a reduction of scorpion surface activity (Polis, 1980; Bradley, 1988; Calderon-Aranda *et al.*, 1996; Araujo *et al.*, 2010; Nime *et al.*, 2013). However, precipitation alone can stimulate scorpion surface activity (Araujo *et al.*, 2010). On the other hand, biotic seasonal factors such as prey abundance and breeding season for scorpions can increase their surface activity (Polis, 1980; Polis and Farley, 1980; Bradley, 1988). Therefore, the influence of biotic and abiotic factors can modify scorpion behaviour, which can result in stings that threaten human health (Chowell *et al.*, 2006).

Studies have detected a seasonal pattern in scorpion sting cases based on morbi-mortality, climatic conditions, and anthropogenic factors. For example, scorpion sting incidence rates peak during the warmest months of the year (Dehesa-Dávila and Possani, 1994; De Sousa *et al.*, 1997; De Roodt *et al.*, 2003; Al-Asmari and Al-Saif, 2004; Chowell *et al.*, 2006; Jahan *et al.*, 2007; Ozkan *et al.*, 2007). Similarly, pluvial precipitation is associated with an increase in scorpion stings, nonetheless the reason for this association is still unknown (Dehesa-Dávila, 1989; De Sousa *et al.*, 1997; Chowell *et al.*, 2006).

The influence of climatic factors in scorpion sting incidence has previously been studied in Mexico, showing a positive correlation between the increase in minimum temperature and scorpion sting incidence (Chowell *et al.*, 2005). However, differences in geographical regions have not yet been studied. Therefore, the present study aims to explore the impact of climate on scorpion sting incidence in several regions of the State of Morelos with different climatic conditions.

2. Materials and methods

An ecological time-series analysis was performed using weekly scorpion stings incidence [International Classification of Diseases (ICD-10) codes T63.2 and X22] and weekly mean meteorological data from 1999 to 2007 in the State of Morelos, Mexico.

Five different climates were identified in Morelos using the climatic cartography from the National Institute of Statistics, Geography and Informatics (Instituto Nacional de Estadística y Geografía, INEGI by its acronym in Spanish). These five categories were clustered to form three main climatic regions: (a) Hot region (HR), which includes the warm-subhumid and semiarid-semiwarm climate region and has an annual mean temperature $> 22\,^{\circ}$C and annual mean precipitation <1000 mm; (b) Warm region (WR) with an annual mean temperature between 12 °C and 22 °C and annual mean precipitation between 1000 and 1500 mm; this climatic region considers semi-warm and subhumid climate; and (c) Cold region (CR) with an annual mean temperature $< 12\,^{\circ}$C and annual mean precipitation >1500 mm, which included temperate-subhumid and semicold-subhumid climate.

The 33 municipalities belonging to the State of Morelos were grouped into one of the three climatic regions previously mentioned (Figure 1). A data base including epidemiological and climatic information was constructed for each climatic region. Scorpion sting reported cases were aggregated by epidemiological week (time variable) for the assembly of municipalities in each region. These cases were obtained from the National Epidemiological Surveillance System (Sistema Único de Información para la Vigilancia Epidemiológica, SUIVE by its acronym in Spanish).

Additionally, daily records were obtained during 1961–2008 of minimum temperature, maximum temperature, and precipitation from 164 meteorological stations from the National Meteorological Service. Researchers from the National Development Academy conducted a quality assurance (QA) of the data through the R-Climdex program (Zhang and Yang, 2004) using the methodology of Díaz and Sánchez (2007). After this analysis only 28 stations were left and out of these, 23 had data during the period of this study. Furthermore, weather stations were located using a Geographic Information System (ArcGIS 2012). Using daily data, minimum and maximum weekly average temperatures and weekly accumulated precipitation were calculated for each climatic region (Figure 1).

Population data was obtained from 2000 to 2010 from the General Census of Population and Housing 2000 and from the Counting of Population and Housing for 1995 and 2005 by INEGI (INEGI, 1995, 2000, 2005, 2010). The annual population by municipality was estimated using interpolation techniques. Those cities that had more than 2500 inhabitants were classified as urban population areas, whereas those with less than 2500 inhabitants were considered rural populations. Percentages of urban and rural population, irrigation areas (hectares), illiteracy, houses with no floor, houses with no toilet, and with no electricity were also estimated to be considered as adjusting variables. Dummy variables for the different years and seasons were created to estimate the difference in scorpion stings among years and seasons.

3. Statistical analysis

A Spearman cross-correlation coefficient was calculated to estimate the association among scorpion sting cases, temperature, and precipitation. Associations between scorpion sting cases and temperature were analysed using a bivariate and multivariate Negative Binomial Regression (NBR) models with different lags. The goodness of fit was assessed for all models, using the log likelihood and the Akaike Information Criterion (AIC).

The variance inflation factor (VIF) was used to test for independence between precipitation and temperature (Kutner *et al.*, 2004). However, the sociodemographic

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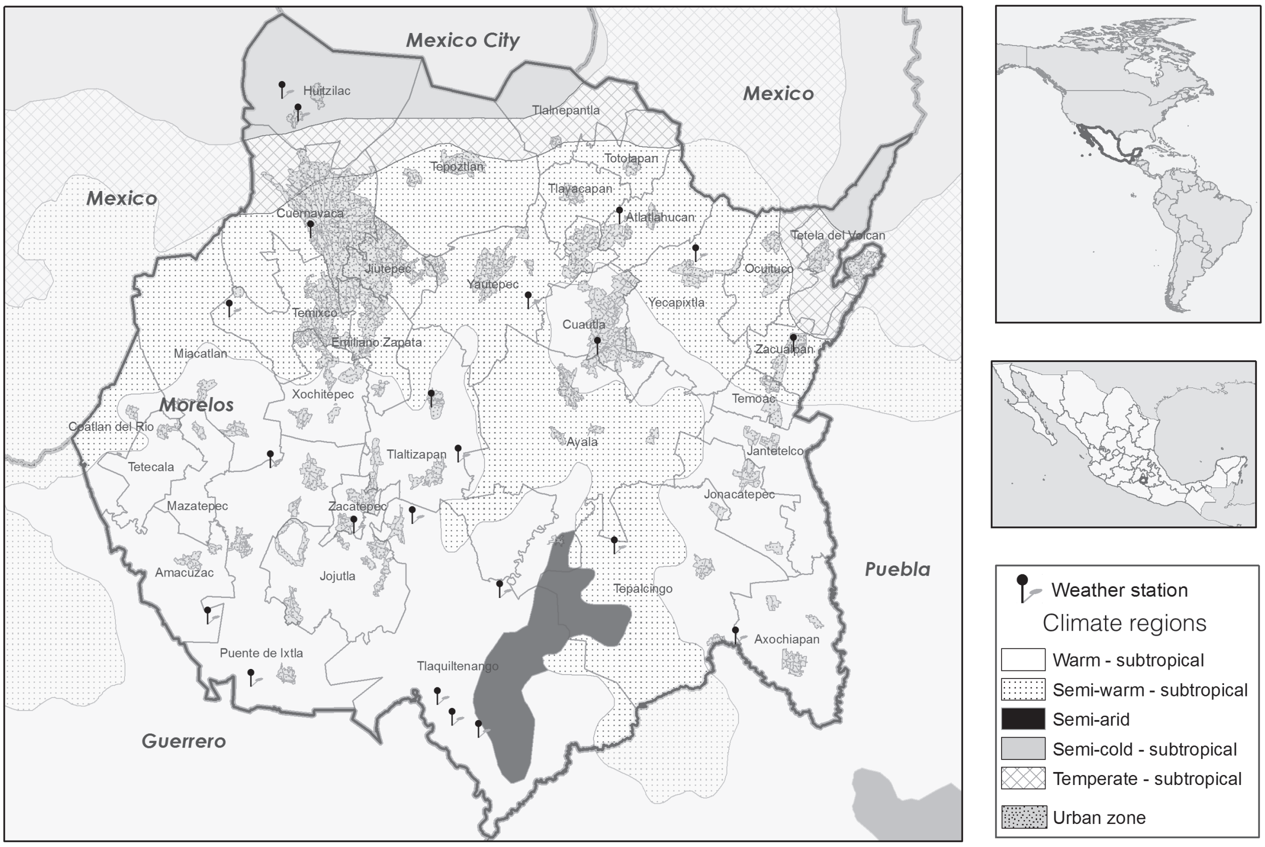

Figure 1. Climatic regions of Morelos.

variables did not satisfy this criterion, thus only the percentage of houses with no floor was left in the model. A Dickey Fuller test was performed on the residuals to avoid correlation by choosing different lags of climatic variables. Finally, the most parsimonious and biologically plausible model was chosen. All the analyses were performed in STATA 11 (Stata 2014), using macros *nberg* (Hilbe 1993).

4. Results

From 1999 to 2007 there were 292 898 scorpion sting cases reported in the state of Morelos, 54% (158 622 cases) of these occurred in the HR, 45.5% (134 212 cases) in the WR and 0.5% (64 cases) in the CR. The annual mean incidence per 100 000 inhabitants was 1523 in the HR, 3010 in the WR and 18.6 in the CR. The mean minimum and maximum temperatures were higher in the HR, whereas the precipitation showed the opposite pattern, registering the highest values in the CR with median differences statistically significant ($p < 0.05$) (Table 1).

During the same period, 36.5% of the population from Morelos lived in the HR, 61.1% in the WR and 2.3% in the CR. Urban population represented 90, 92 and 73% in each region, respectively. The percentage of irrigation area, illiteracy, houses with no floor, houses with no toilet and with no electricity varied between each region and are presented in Table 1.

Figure 2 shows the weekly variation of minimum temperature, maximum temperature, precipitation and scorpion sting cases by climatic region. The months of July through September had more rain along with May and June, which were also the hottest. The highest scorpion sting incidence was observed around week 12 + 2 (March) and week 43 + 2 (October).

The correlation analysis showed a positive and significant association between scorpion sting cases and all climatic variables in the HR and WR, but not in the CR, where only the minimum temperature was statistically significant. In the HR, both temperature indicators were strongly correlated with scorpion sting cases (0.59 for minimum and 0.60 for maximum, $p < 0.05$); in the WR, minimum temperature showed the highest correlation (0.70 for minimum and 0.46 for maximum, $p < 0.05$), and in the CR only minimum temperature had a significant weak correlation with scorpion sting cases (0.09, $p < 0.05$) (Table 2).

Crude models showed a significant relationship between temperature and scorpion stings in the HR, with 7.5% (95% CI: 6.7–8.4) per 1 °C increase in minimum temperature and 9.2% (95% CI: 8.2–10.3) per each 1 °C in maximum temperature during the same week (lag-0); the effect of precipitation was statistically not significant. In the WR, the percent change of weekly scorpion sting incidence for 1 °C increase in minimum temperature was 11.3% change (95% CI: 10.2–12.3), 7.3% change (95% CI: 6.0–8.6) for 1 °C increase in maximum temperature and 2.1% (95% CI: 1.0–3.3) for each 1 mm increase in precipitation (lag-0).

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Table 1. Summary statistics of demographic, epidemiological and climatic variables by region, Morelos, Mexico, 1999–2007

Variables	Hot	Warm	Cold
Demographic			
Population *n* (%)	595 443 (37.1)	973 783 (60.5)	38 941 (2.4)
Urban population (%)	482 128 (90)	892 038 (92)	28 555 (73)
Rural population (%)	113 315 (10)	81 745 (11)	10 386 (27)
Irrigation area (hectares)	2012	1042	4
Adult literacy (%)	11.59	8.42	8.04
Houses without floor (%)	15.51	13.38	19.19
Houses without sanitary (%)	11.07	10.08	13.34
Houses without electricity (%)	2.72	3.80	6.09
Epidemiological			
Scorpion sting incidence	158 622	134 212	64
Incidence rate[a]	3010	1523	18.6
Weekly mean incidence ± SD	339 ± 113	287 ± 93	0.14 ± 0.42
Climatic			
Minimum temperature (°C)[b] ± SD	15 ± 3	12 ± 2	9 ± 2
Maximum temperature (°C)[c] ± SD	33 ± 2	28 ± 2	23 ± 2
Precipitation (mm)[d] ± SD	17 ± 23	20 ± 28	28 ± 40

[a]Per 100 000 inhabitants. [b]Weekly mean minimum temperature. [c]Weekly mean maximum temperature. [d]Weekly mean accumulated precipitation.

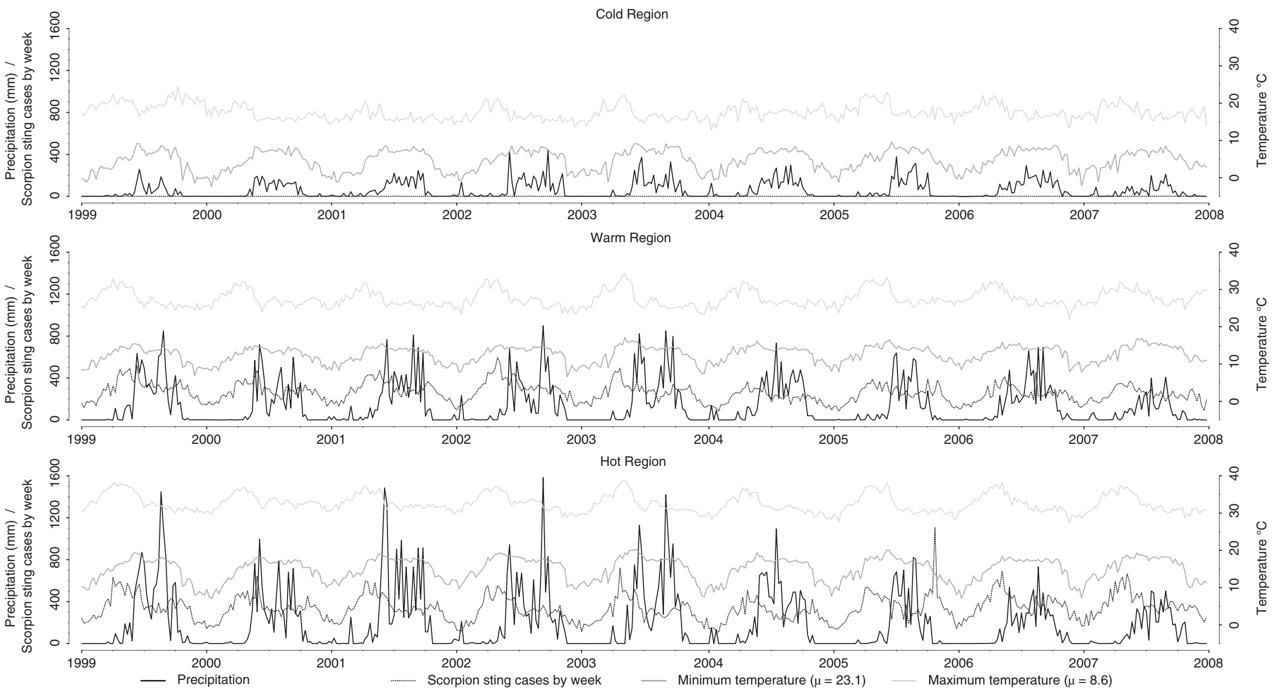

Figure 2. Time series of weekly scorpion sting incidence, temperature and precipitation by climatic regions, Morelos, Mexico, 1999 to 2007.

In the CR only the minimum temperature showed a significant increase in scorpion sting incidence of 18.2% (95% CI: 4.0–34.4) at lag-0. Table 3 presents the results for lag-1 and lag-2 (Table 3).

After adjusting by sociodemographic variables, models showed that 1 °C increase in minimum temperature, increased the weekly scorpion sting cases by 6.2% (ranging from 5.00 to 7.50) and 7.6% (ranging from 6.00 to 9.20) in the HR and WR, respectively. For each increase of 1 °C in maximum temperature, scorpion sting cases increased in 9.2% (ranging from 8.20 to 10.30) and 7.3% (ranging from 6.00 to 8.60) in the same regions. The models stratified by season showed a highest association during spring season (Table 4).

5. Discussion

Although scorpion stings can be prevented and should be considered a priority for research to create a successful health program, this is the first study conducted in the endemic regions of Morelos that associates the increase of scorpion sting cases with changes in temperature and precipitation. Previous studies have found an association among scorpion sting incidence, climatic, and geographic characteristics (Camacho-Ramírez *et al.*, 2007; Gómez and Otero, 2007; Charrab *et al.*, 2009; Secretaría de Salud, 2012). The results of this study are similar with those obtained in the State of Colima, Mexico (Chowell *et al.*, 2005, 2006), where changes in the minimum temperature

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Table 2. Correlation between weekly scorpion sting incidence and climatic variables by region, Cuernavaca, Morelos, 1999–2007[a]

Variables	Hot		Warm		Cold	
	R	*p* value	*R*	*p* value	*R*	*p* value
Minimum temperature (°C)	0.59	0.00	0.70	0.00	0.09	0.03
Maximum temperature (°C)	0.60	0.00	0.46	0.00	−0.00	0.95
Precipitation (mm)	0.27	0.00	0.39	0.00	0.08	0.07

[a]Spearman correlation.

Table 3. Percentage change of scorpion sting cases per each 1 °C of temperature. Crude Model: Morelos, Mexico, 1999–2007

Variable	Hot region		Warm region		Cold region	
	% of change	95% CI	% of change	95% CI	% of change	95% CI
Bivariate Model[a]						
Minimum temperature (°C)						
Lag 0	7.50	6.70 to 8.40	11.30	10.20 to 12.30	18.20	4.00 to 34.40
Lag 1	7.00	6.20 to 7.90	10.40	9.30 to 11.50	15.40	1.80 to 30.90
Lag 2	6.40	5.50 to 7.30	9.80	8.70 to 11.00	15.70	2.00 to 31.20
Maximum temperature (°C)						
Lag 0	9.20	8.20 to 10.30	7.30	6.00 to 8.60	−0.00	−0.12 to 13.10
Lag 1	9.70	8.70 to 10.70	7.40	6.10 to 8.70	5.10	−0.06 to 18.70
Lag 2	9.80	8.80 to 10.80	8.00	6.70 to 9.20	2.70	−0.09 to 16.00
Precipitation (mm)						
Lag 0	1.30	−0.00 to 2.70	2.10	1.00 to 3.30	4.70	−0.00 to1.10
Lag 1	0.80	−0.00–2.10	2.00	0.90 to 3.10	5.40	−0.00 to 11.90
Lag 2	0.30	−0.01 to 1.60	1.70	0.60 to 2.80	2.80	−0.03 to 9.90

explains the higher percentage of variability in scorpion sting incidence.

In the present study, models with minimum temperature presented the most accurate prediction, probably this is because scorpions are photoblastic organisms and they become more active when the minimum temperature reaches an optimal value for the development of their biological cycles (Polis, 1980; Chowell *et al.*, 2005; Araujo *et al.*, 2010).

Regarding the seasonality, authors reported that in the State of Guanajuato scorpions have a predilection for warm and dry climate (Castillo-Pérez *et al.*, 2007). This is confirmed in this study because during spring, the season with warm and dry climatic characteristics, the highest number of cases is reported in Morelos. However, Chowell *et al.* (2005), found a higher incidence during the summer (months of June through October). Also a study in Iran, found a higher incidence of scorpion stings (46%) in the summer and the lowest (4.42%) in winter (Taj *et al.*, 2012). Differences in the findings of each study could be explained by differences in climatic conditions between the studied regions.

Adjusted models also included percentage of agricultural irrigation areas, considering that land use affects the activity of the species because involve more contact with scorpions (Chowell *et al.*, 2005; Villegas-Arrizón *et al.*, 2009). However, according to our analysis, the irrigation area had a protective effect, which could be attributed to the fact that scorpions have abundance of prey in these areas, mainly insects and spiders, and do not need to sting humans (Polis, 1980; Araujo *et al.*, 2010), Another explanation may be that most of people working in agriculture are adults, and scorpion stings do not represent a deadly risk because they are capable of solving this issue without specialized medical assistance (Villegas-Arrizón *et al.*, 2009; García-Barbosa *et al.*, 2010).

One factors considered as covariables to explain the changes in the scorpion sting cases was the percentage of health services because. Several authors have documented that there is an underreporting of scorpion sting incidence because of lack of health services. Also because in endemic regions people, especially the elderly, use home remedies to treat scorpion stings since most of the times these are not lethal (Camacho-Ramírez *et al.*, 2007; Celis *et al.*, 2007; Chowell *et al.*, 2005; Santibáñez-López *et al.*, 2011). In the CR, the analysis showed a positive association, a probable cause for this is the ability of the population to access health services in this region. Moreover, some of the economic activities (e.g. house building job) performed by the population of this area increase their probability of scorpion stings (Camacho-Ramírez *et al.*, 2007; Santibáñez-López *et al.*, 2011).

Another covariable considered was the percentage of houses with no floor, because it has been associated with scorpion sting incidence, mainly in rural and indigenous areas. This is an important factor to consider because poor housing conditions are suitable for scorpion survival, which increases the probability of human contact (García-Barbosa *et al.*, 2010). The rest of the sociodemographic characteristics considered as covariables, like illiteracy, houses with no toilet and of houses with no electricity, was excluded because of multicollinearity.

There are limitations in the use of the data generated by the surveillance system. The available information did

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Table 4. Percentage change in scorpion sting cases per each 1 °C increase in temperature. Adjusted model: Morelos, Mexico, 1999–2007

Variable	Hot region		Warm region		Cold region	
	% of change	95% CI	% of change	95% CI	% of change	95% CI
Adjusted model 1[a]						
Minimum temperature (°C), Lag 2[a]	6.20	5.00 to 7.50	7.60	6.00 to 9.20	0.97	0.80 to 1.17
Precipitation (mm), Lag 1	−0.02	−0.03 to −0.01	−0.00	−0.00 to 0.10	2.0	−0.05 to 10.3
% House without floor	0.30	−0.00 to 0.90	1.50	0.90 to 2.00	−0.11	−0.16 to −0.00
Season[c]						
Spring	36.30	25.30 to 48.20	37.40	26.90 to 48.90	4.66	1.34 to 16.16
Summer	−0.04	−0.12 to 5.0	2.90	−0.05 to 12.20	4.24	1.10 to 16.24
Autumn	3.60	−0.03 to 11.0	4.90	0.01 to 11.80	209.20	−0.02 to 877.80
Adjusted model 2[b]						
Maximum temperature (°C), Lag 2[b]	9.80	8.30 to 11.30	5.10	3.50 to 6.60	−0.06	−0.20 to 11.10
Precipitation (mm), Lag 1	0.40	−0.01 to 1.50	1.30	0.30 to 2.30	1.10	−0.06 to 8.90
% House without floor	−0.00	−0.01 to −0.00	1.70	1.10 to 2.30	−0.11	−0.16 to −0.06
Season[c]						
Spring	25.80	16.10 to 36.30	53.0	41.40 to 65.60	5.15	1.65 to 16.07
Summer	22.20	13.80 to 31.20	29.40	20.0 to 39.40	3.85	1.25 to 11.84
Autumn	35.20	27.50 to 43.50	25.30	17.70 to 33.50	177.90	−0.03 to 699.80

[a]Adjusted model with minimum temperature. [b]Adjusted model with maximum temperature. [c]Winter as the reference category.

not allow to determine whether the reported scorpion sting cases are the cases presented in the municipalities of the present study. However, there is no reason to believe that the degree of underreporting varied over time or there are differences in reporting over the years and over the regions. Thus the under report of the number of cases would not be expected to cause bias.

Another limitation is the use of time series where data is correlated, especially when long periods of times are considered. However, the variables that presented collinearity were excluded from the final model.

6. Conclusions

The results observed in this study suggest the existence of temporal patterns in scorpion sting incidence and the association of the cases with temperature and precipitation. The results also revealed that the minimum temperature is the climatic metric mainly associated with the increase in scorpion sting incidence and it also shows that changes in precipitation could play an important role in certain regions, especially when other factors are considered, such as socioeconomic activities and housing conditions.

During the last years, epidemiologists and ecologists have been using climatic variables to predict the behaviour of several diseases such as vector-borne diseases (Chowell *et al.*, 2005). In this way, the results presented here may help to design, implement or improve preventive measures and control programs in the studied regions (Secretaría de Salud, 2008b). For instance, the timing of these measurements could be planned based on the climatic changes observed in scorpion sting incidence.

Future research should consider another adjusting variables that can help to further explain the changes in scorpions stings, like socioeconomic and sociodemographic variables. It could also be useful to gather data about the species that are mainly involved in scorpion sting incidence in the population to identifying those related to high morbi-mortality. Additionally, the methodology used in this study might be helpful to conduct future studies analysing small geographic areas with high scorpion sting incidence.

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