

Predicting scorpion sting incidence in an endemic region using climatological variables*

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Abstract

Scorpionism is a public health problem in several regions of the world. The highest mortality, with over 1000 deaths per year, has been reported in Mexico. We analysed the significance of climatological variables to predict the incidence of scorpion stings in humans in the state of Colima (Mexico) for the years 2000–2001. The pluvial precipitation (mm), the evaporation (mm), and the mean, maximum, and minimum temperatures (°C) were obtained from local meteorological offices. There are approximately 3 stings/year per 1000 people in municipalities of Colima and Villa de Alvarez and about 18–30 stings/year per 1000 people in the rest of the municipalities. There is very little rain and there are few stings in the winter when the minimum temperature is below about 16°C. The number of scorpion stings is independent of the actual rainfall when this is above 30 mm/month. Using multiple linear regression, we used a backward model selection procedure to estimate that the minimum temperature is correlated with scorpion sting incidence with a statistically significance of 95%. We briefly discuss the application of predictive models of scorpion sting incidence in the appropriate allocation of antivenom serum in hospital clinics.

Keywords: *Scorpion, climate, temperature, rainfall, correlation*

Introduction

Scorpionism is a public health problem in North and South Africa, India, Middle East, Turkey, France, Spain, Mongolia, China, Central Asia, and America (Russell 2001). The highest mortality rate of up to 1000 deaths per year has been reported in Mexico (Bush & Charles 2003). Around the world almost 1500 scorpion species have been reported, but only about 25 species are dangerous to humans (De Roodt et al. 2003). In Mexico, there are approximately 134 species or sub-species of scorpions (30 of which belong to the genus *Centruroides* but only eight are known to be dangerous to humans (Dehesa-Davila & Possani 1994). The venomous species are found in 11 Mexican states bordering the Pacific Ocean (Hoffmann 1936; Hoffmann & Nieto 1939; Mazzoti & Bravo-Becherelle 1963; Dehesa-Davila &

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Possani 1994; Zarate-Aguilar & Maraboto-Martinez 1997; Chavez-Haro 1998). Also, in the South-western United States and adjacent Mexico, stings from *Centruroides exilicauda* are dangerous to humans.

Scorpions are poisonous arthropods found in many habitats. They feed at night on a variety of insects and other scorpions. The larger scorpions may feed on small vertebrates such as lizards, snakes and mice. Scorpions have a long gestation period, ranging from several months to a year and a half. A female scorpion gives birth to about 25–35 young on the average, and their average life expectancy ranges from three to five years, but some species live at least 10–15 years (Polis 1990). The scorpions use their venom for both predation and defense. The venom is contained in glands located in the telson, which has a bulb-shaped structure.

The temporal incidence of scorpion stings shows a strong seasonal pattern that correlates to climatological variables. An increase in scorpion activity in the warmer months has been observed in the state of Guanajuato, Mexico, where the dangerous scorpion species *Centruroides infamatus infamatus* inhabits (Dehesa-Davila & Possani 1994), and in Argentina, where an increase in the scorpion sting incidence caused by *Tityus trivittatus* is observed in the warmer months of October through April (De Roodt et al. 2003).

The impact of rainfall is more ambiguous. Mazzoti and Bravo-Becherelle (1963) report a higher scorpion sting incidence during the rainy season. They explain this increase in scorpion activity to the flooding from the rainfall of the burrows where scorpions live. On the contrary, Dehesa-Davila (1989) associates the beginning of the rainy season with a decrease in the number of scorpion stings.

The first author and colleagues have reported on the clinical and epidemiological characteristics following scorpion sting by *Centruroides limpidus tecomanus* in the state of Colima, Mexico (Chowell et al. 2004). The pediatric electrocardiograph abnormalities following envenomation by the same scorpion species have also been reported previously (Diaz-Duenas et al. 2004). In this paper, we present the first quantitative analysis on the association between the incidence of scorpion stings and climatological variables. We used data on the daily number of scorpion stings in the state of Colima, Mexico, during the period 2000–2001 to systematically assess the use of climatological variables in predictive models of scorpion sting incidence using aggregated and regional data. Finally, we briefly discuss the application of predictive models of scorpion sting incidence in the appropriate allocation of antivenom serum in hospital clinics.

Materials and methods

We used the daily number of treated scorpion stings (in humans) reported by the hospitals of the Health Ministry (SSA) and the Mexican Institute of Public Health (IMSS) during 2000 and 2001. These hospitals provide service to 95% of the population in the state of Colima, Mexico.

The state of Colima is located on the central pacific coast, is composed of 10 municipalities, and has a tropical climate and a population of approximately 488,028 inhabitants (INEGI 1995). The number of cases of scorpion sting shows a seasonal pattern that correlates well with the temperature and the rainy season. Most of the cases occurred in the coastal municipalities of Manzanillo (33.13%), Tecomán (24.40%), and Armería (12.03%) where temperatures surpass 26°C in the months of June through October (see Figure 1), period in which the scorpion activity increases (Chowell et al. 2004). The scorpion sting incidence was normalized by the total population and expressed as cases per thousand.

We considered the correlation of the number of scorpion stings with the climatological variables: precipitation (mm), mean temperature (°C), maximum temperature, minimum

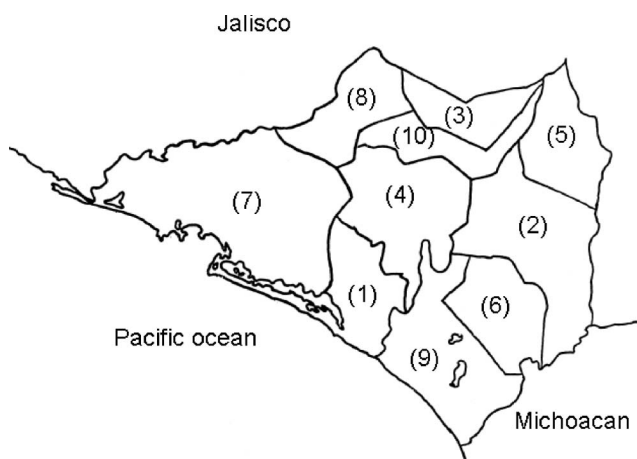


Figure 1. Map of the state of Colima, Mexico with divisions by municipalities. Most of the scorpion stings occurred in the municipalities of Manzanillo (7) (33.13%), Tecomán (9) (24.40%), and Armería (1) (12.03%), where the mean annual temperature is greater than 26°C (INEGI 1995), followed by Cuauhtémoc (5) (6.59%), Comala (3) (6.51%), Coquimatlán (4) (5.96%), Colima (2) (4.70%), Minatitlán (8) (3.62%), Villa de Alvarez (10) (1.76%), and Ixtlahuacán (6) (1.30%).

temperature, and evaporation (mm). The data comprises 24 months (2000–2001) with month one being the first month of the year 2000 (Figure 2). Such data was collected from eight local meteorological offices located in eight of the 10 municipalities in Colima. The precipitation and temperature showed a strong seasonal pattern reaching their highest values in the summer. The highest temperatures are observed in the municipalities bordering the coastal region namely the municipalities of Manzanillo, Armería, and Tecomán.

Using aggregated data on scorpion sting incidence and the mean of the climatological variables obtained from local meteorological offices, we first carried out a univariate regression analysis on each of the variables to study the amount of explained variance from each variable in the absence of the other climatological variables. We then performed a multiple linear regression analysis with a backward elimination model selection procedure (Neter & Wasserman 1974) using as predictors the six climatological variables mentioned above. We then eliminated sequentially predictors at the 90% significance level or less leaving a model with variables significant at the 95% or higher. We also used data from the year 2000 to predict the number of scorpion stings in 2001.

Results

We analysed the pairwise correlations between each pair of climatological variables (see Figure 3) and between each of the climatological variables and scorpion sting incidence in each of the municipalities.

The following are our main observations:

- There are approximately about 3 stings/year per 1000 people in the cities (Colima and Villa de Alvarez), and between 18–30 stings/year per 1000 people in the rest of the municipalities.
- There are very few stings or rain in the winter when the minimum temperature is below about 16°C (Figure 4).

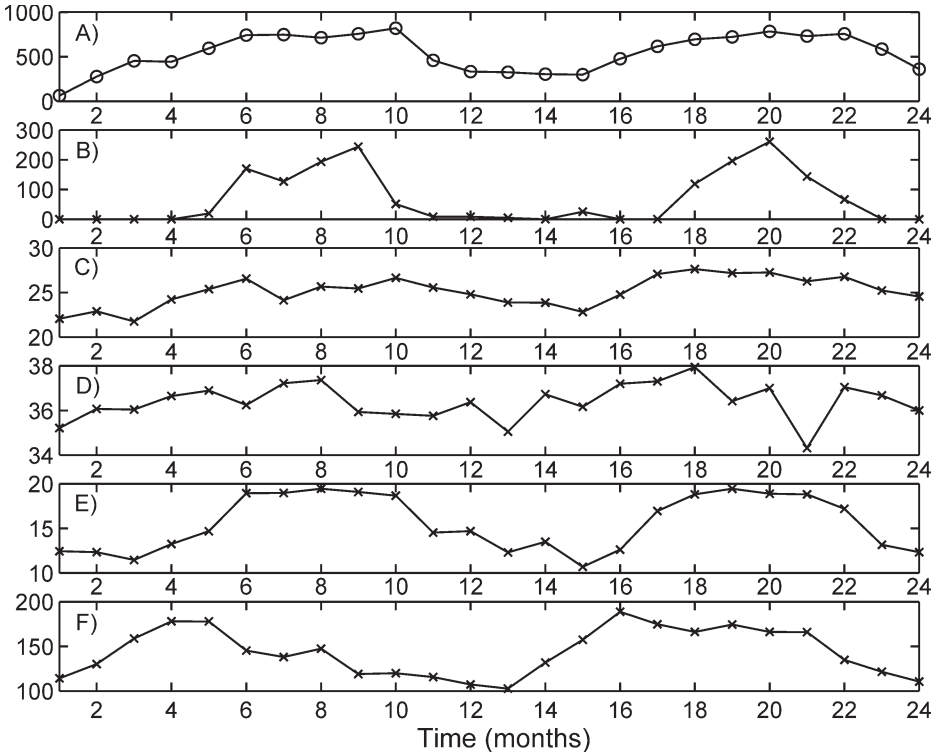


Figure 2. Climatological variables for the period 2000–2001 for the state of Colima, Mexico. Here, we show the average of the measurements obtained from eight local meteorological offices located in eight of the 10 municipalities: Armería, Colima, Comala, Coquimatlán, Cuauhtémoc, Ixtlahuacán, Minatitlán, and Tecomán. A) Monthly incidence of scorpion stings during the period 2000–2001; B) Pluvial precipitation (mm); C) Mean temperature (°C); D) Maximum temperature; E) Minimum temperature; F) Evaporation (mm).

- The number of stings increases monotonically with the minimum temperature (Figure 5).
- When the rainfall is above 30 mm/month, the number of scorpion stings is independent of the actual rainfall (Figure 4).
- Evaporation showed no significant correlation with scorpion sting incidence (Figure 5).

To estimate the importance of the heterogeneity of Colima, such as rural vs. urban or coastal vs. non-coastal communities, we studied the relationship between the total scorpion sting incidence as a function of the total population size per municipality. The total number of scorpion stings during the study period in each of the municipalities was proportional to the population size of eight out of the 10 municipalities in which the state of Colima, Mexico is divided (see Figure 6), namely the municipalities of Ameria, Comala, Coquimatlán, Cuauhtémoc, Ixtlahuacán, Manzanillo, Minatitlán and Tecomán. We refer to the region comprised by these municipalities as Region 1.

For these municipalities, the total number of scorpion stings during the study period and the population size (given in Table I) were related as follows:

$$\text{Total number of scorpion stings (region 1)} = 106.95 + 0.04 (\text{Population size}) \quad (1)$$

an equation that explains 98.60% of the observed variance.

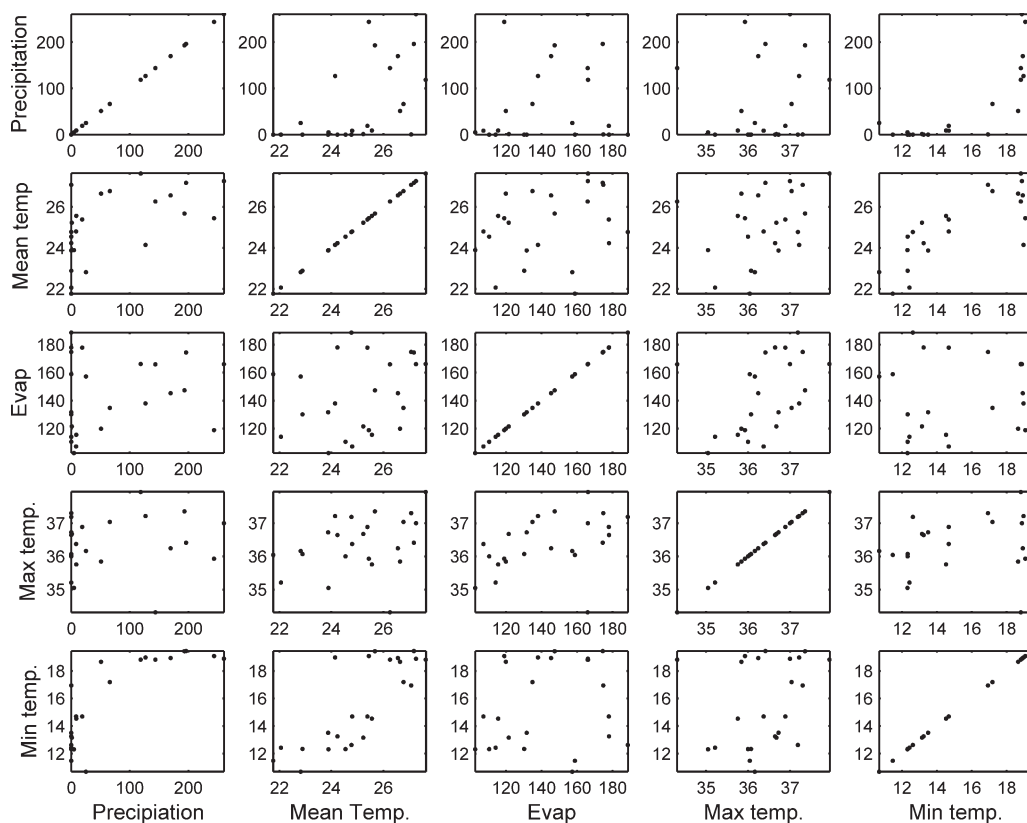


Figure 3. Pairwise correlation plots between each of the climatological variables using the average of the measurements obtained from eight local meteorological offices located in eight of the 10 municipalities: Armería, Colima, Comala, Coquimatlán, Cuauhtémoc, Ixtlahuacán, Minatitlán, and Tecomán.

There are fewer scorpion stings in the urban municipalities of Colima and Villa de Alvarez (Region 2) (Figure 6). The above equation overestimates the number of scorpion stings in Colima and Villa de Alvarez by 86.89% and 91.40%, respectively. Such discrepancies are probably due to differences in spatial heterogeneity (explained in the Discussion). Because of these differences, we analysed these two regions separately. To account for differences in the population size of the municipalities, we normalized the number of scorpion stings by the total population and expressed them as cases per thousand.

We analysed the aggregated scorpion sting incidence data in Region 1 to systematically determine the statistical significance of the climatological variables as predictors of scorpion sting incidence. We averaged the climatological variables obtained from eight local meteorological offices located in eight of the 10 municipalities. The climatological variables with the highest correlation coefficients are the minimum temperature ($r=0.87$), mean temperature ($r=0.80$) and precipitation ($r=0.72$) (see Figure 5). Before carrying out our regression analysis, we examined the scatter plots of each of the climatological variables and the scorpion sting incidence for any non-linear relationships. We applied the squared root transformation (SQRT) to the variable precipitation to partially adjust for the non-linear relationship (Figure 5).

We carried out a univariate linear regression analysis on each of the climatological variables available. The maximum explained variance is given by the minimum temperature (75.41%)

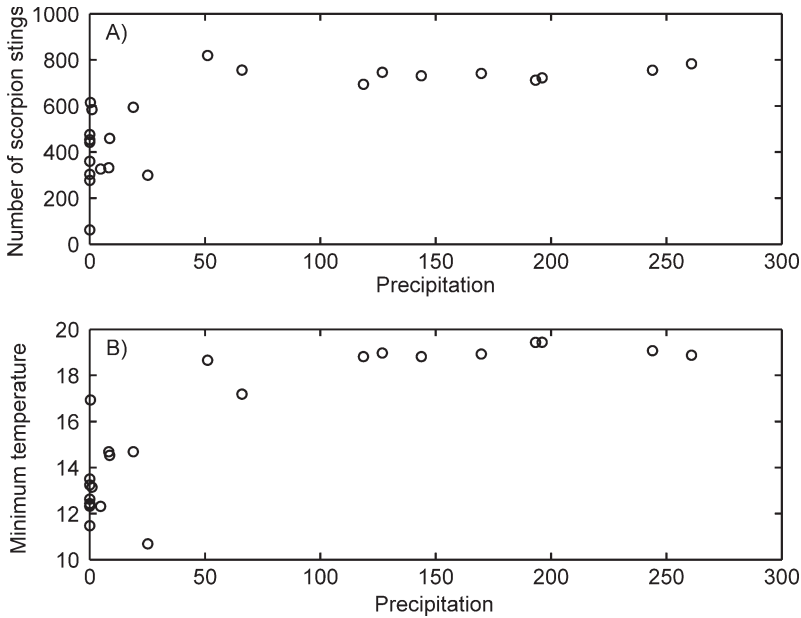


Figure 4. (A) The correlation plot between precipitation and the total number of scorpions stings per month; (B) the correlation plot between precipitation and minimum temperature. We use the average of the measurements obtained from eight local meteorological offices located in eight of the 10 municipalities: Armería, Colima, Comala, Coquimatlán, Cuauhtémoc, Ixtlahuacán, Minatitlán, and Tecomán. There are very few stings or rain in the winter when the minimum temperature is below about 16°C. When the rainfall is above 30 mm/month, the number of scorpion stings is independent of the actual rainfall.

followed by mean temperature (63.25%), precipitation (60.58%), maximum temperature (10.47%), and evaporation (11.00%). A multiple linear regression analysis on all the climatological variables results in the following model for the number of stings per month per 1000 people:

$$\begin{aligned}
 \text{Scorpion sting incidence (Region 1)} = & -4.51 + 0.02 \text{ SQRT (Precipitation)} \\
 & + 0.11 \text{ (Mean temp.)} \\
 & + 0.001 \text{ (Evaporation)} + 0.03 \text{ (Maximum temp.)} \\
 & + 0.10 \text{ (Minimum temp.)}
 \end{aligned} \tag{2}$$

which explains 81.07% of the observed variance.

Following the backward elimination model selection procedure (Neter & Wasserman 1974), we proceeded to eliminate sequentially the variables with significance of 90% or less starting from the least significant variable. The sequence in which non-significant variables were eliminated is as follows: Maximum temperature, precipitation, evaporation, and mean temperature leaving in the model only one significant predictor at the 95% level: The minimum temperature (°C).

The resulting model for Region 1 for the number of stings per month per 1000 people is:

$$\text{Scorpion sting incidence (Region 1)} = -1.23 + 0.20 \text{ (Minimum temp.)} \tag{3}$$

This model was able to explain 75.41% of the observed variance with $p < 0.0001$. Figure 7 shows the fit of the model (3) to the data, the model prediction for year 2001 compared to

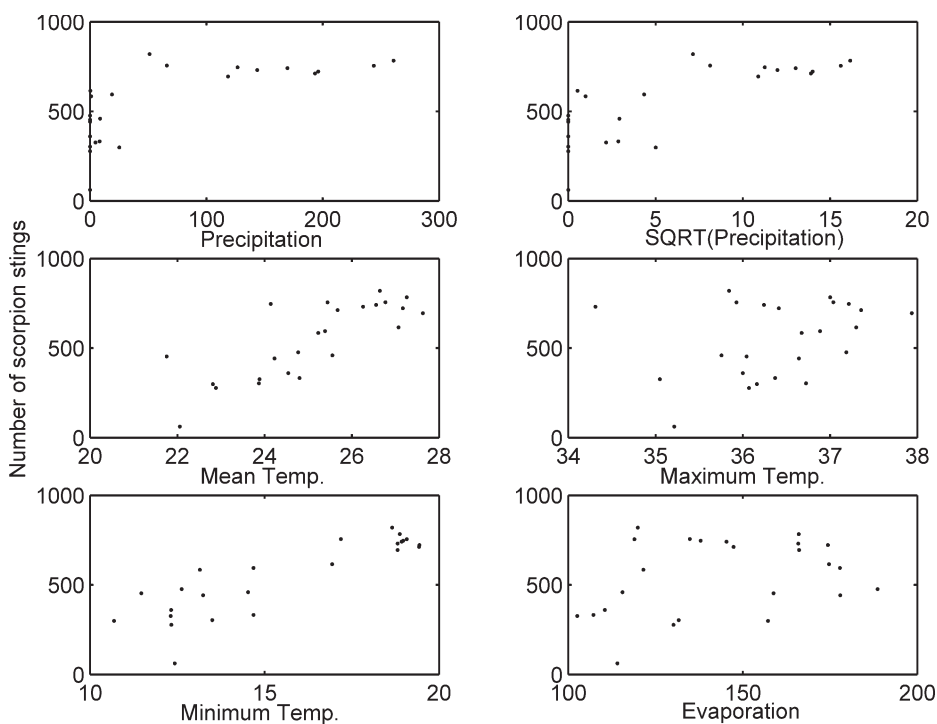


Figure 5. The number of cases of scorpion stings as a function of the climatological variables: Precipitation (mm), mean temperature (°C), maximum temperature, minimum temperature, and evaporation (mm). The linear trends support the use of multiple regression analysis. A weak relationship between the number of scorpion stings and precipitation is observed. The non-linear relationship between the number of scorpion stings and precipitation disappeared after using the square root (SQRT) transformation.

actual data when the model is calibrated using the data for year 2000, and the corresponding standardized residuals as a function of time.

The plot of the standardized residuals showed common variance and no apparent structure in the errors. Similarly, for Region 2 (Colima and Villa de Alvarez) we obtained the following model for the number of stings per month per 1000 people:

$$\text{Scorpion sting incidence (Region 2)} = 0.02 + 0.01 (\text{Minimum temp.}) \tag{4}$$

This model was able to explain 14.17% of the observed variance with $p < 0.0001$ (Figure 8). We only used climatological information from the municipality of Colima (state capital) because climatological information for the municipality of Villa de Alvarez was not available. This may explain the smaller explained variance of the model.

Discussion

While there are some studies that have reported on the association of climatological variables and the emergence and re-emergence of vector-borne infectious diseases including Dengue (Gubler et al. 2001; Nagao et al. 2003; Depradine & Lovell 2004) and malaria (Hay et al. 2002), to the best of our knowledge, this is the first attempt to quantify the predictive power of climatological variables on the incidence of scorpion stings in humans in an endemic region.

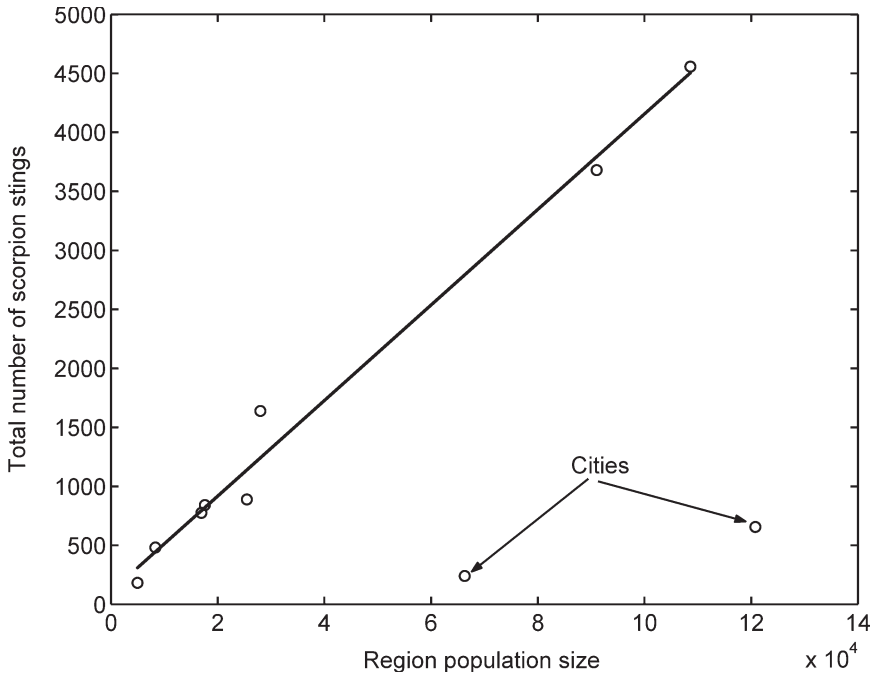


Figure 6. The total number of scorpion stings in each of the municipalities of the state of Colima, Mexico, during the study period as a function of the population per municipality density. The circles are the data for the 10 municipalities. While the total number of scorpion stings is proportional to population size for eight of the 10 municipalities, this is not observed for the municipalities of Colima and Villa de Alvarez (see Figure 1).

Table I. The population size and the scorpion sting incidence in each of the municipalities in which the state of Colima (Mexico) is divided.

Municipality	Population size	Scorpion stings in 2001	Scorpion stings in 2002
Armería	28015	737	901
Colima	120781	291	364
Comala	17601	414	427
Coquimatlán	16939	389	385
Cauhtémoc	25462	508	380
Ixtlahuacán	4989	67	115
Minatitlán	8321	234	247
Manzanillo	108584	2093	2464
Tecomán	66300	1950	1730
Villa de Alvarez	66300	129	111

We have assessed the significance of five climatological variables in the prediction of scorpion sting incidence in an endemic region where the scorpion species *Centruroides limpidus tecomanus* inhabits. The study included those cases of scorpion sting reported in hospitals of the Health Ministry and the Mexican Institute of Public Health, which in conjunction provide service to 95% of the total population in the state of Colima, Mexico (see Figure 1).

The scorpion sting incidence in the municipalities of America, Comala, Coquimatlán, Cauhtémoc, Ixtlahuacán, Manzanillo, Minatitlán and Tecomán were much higher than for

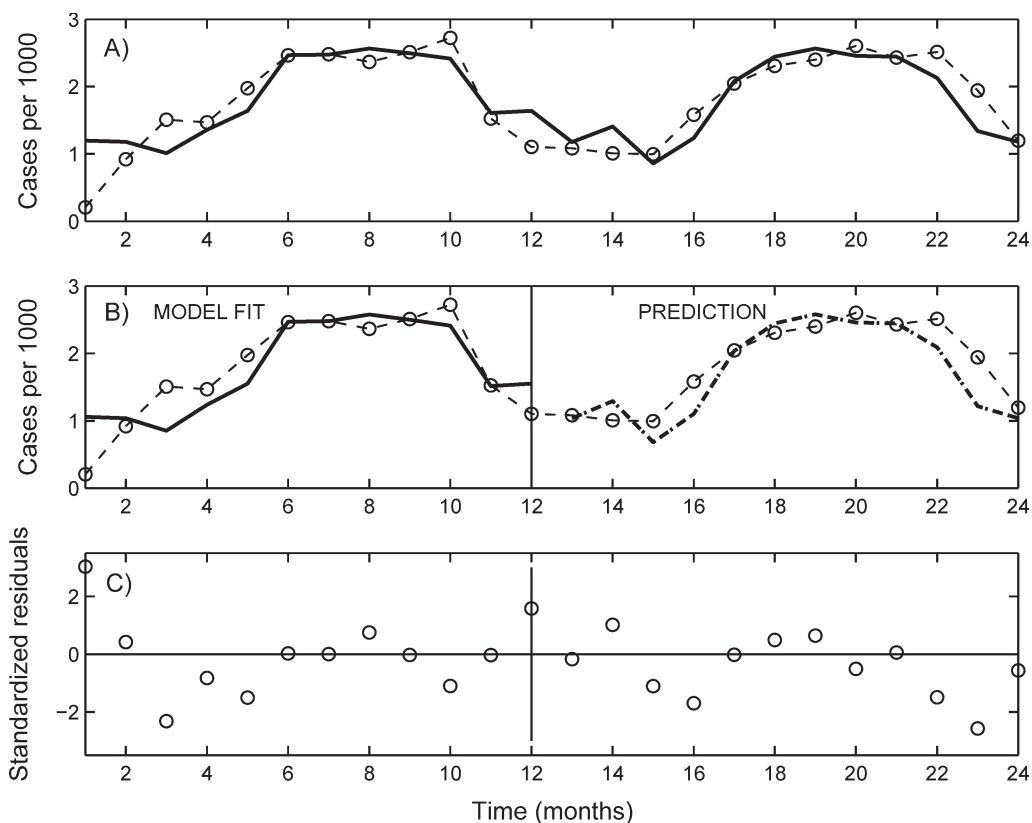


Figure 7. (A) The scorpion sting incidence in the the region comprised by the municipalities of Armería, Colima, Comala, Coquimatlán, Cuauhtémoc, Ixtlahuacán, Minatitlán, and Tecomán (region 1) during the period 2000–2001. The data are the circles and the linear regression model with minimum temperature ($^{\circ}\text{C}$) is the solid line. (B) The model prediction for the year 2001 (dash-dot) when this is calibrated using the data for year 2000 (solid line). (C) The standardized residuals obtained from the model fit and prediction in (B) during the period 2000–2001 show common variance and no apparent structure.

the municipalities of Colima (state capital) and Villa de Alvarez. This difference is probably due to the several factors including urbanization levels in these cities but other factors could be responsible for this observed difference including the presence of a lower scorpion density in the city due to the smaller number of suitable environments for their subsistence; the number of people occupied in agricultural activities in the city is minimal; and the lower socio-economic level in rural regions correlates with lower hygiene in households.

Our results indicate a strong positive association between minimum temperature and scorpion activity (Figure 2). For the aggregated state data, the highest scorpion sting incidence was reached when the minimum temperature of 19.43°C was reached in the year 2000 and 18.81°C in 2001. This correlation is in agreement with other studies (Dehesa-Davila & Possani 1994; De Roodt et al. 2003).

We observed ‘threshold’ behavior between pluvial precipitation and scorpion sting incidence. When the rainfall <30 mm/month, there were very few scorpion stings. When rainfall >30 mm/month, the scorpion sting incidence was independent of the actual rainfall. This may be due to the rainfall disturbing the scorpions, forcing them to search for new

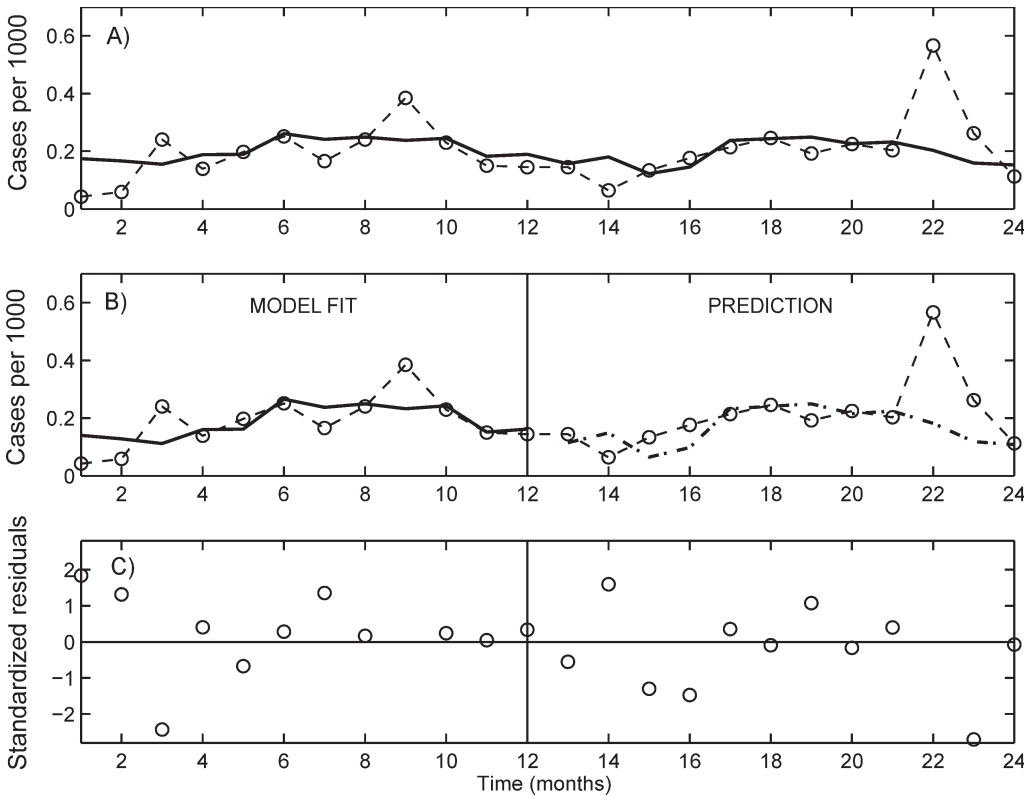


Figure 8. (A) The scorpion sting incidence in the the region comprised by the municipalities of Colima and Villa de Alvarez (region 2) during the period 2000–2001. The data are the circles and the linear regression model with minimum temperature ($^{\circ}\text{C}$) is the solid line. (B) The model prediction for the year 2001 (dash-dot) when this is calibrated using the data for year 2000 (solid line). (C) The standardized residuals obtained from the model fit and prediction in (B) during the period 2000–2001 show common variance and no apparent structure. We only used climatological information from the municipality of Colima (state capital) because climatological information for the municipality of Villa de Alvarez was not available.

refuges. The rainy season has been observed to be positively correlated to scorpion activity by Mazzoti and Bravo-Becherelle (1963) and Chowell et al. (2004). However Dehesa-Davila (1989) observed that there was a decrease in the number of scorpion stings in the state of Guanajuato, Mexico at the beginning of the rainy season.

The resulting predictive equation for the scorpion sting incidence in Region 1 explains 75% of the observed variance. This indicates that the scorpion activity in the state of Colima Mexico is greatly associated to temperature changes while other sociological, behavioral or economic factors not included in this study could be accounting for a small fraction of the variability not captured by meteorological information. However, other social and economic factors may be substantially correlated with climatological variables. In the present study most of the scorpion stings occurred inside houses (76.18%) and during agricultural activities (16.96%). Therefore, the quality of the households is an important factor in the number of scorpion stings. The quality of households is often quantified using the Premise Condition Indexed (PCI) proposed by Tun-Lin et al. (1995). The PCI considers the maintenance, hygiene and shadow aspects of the household. Each of these aspects is quantified as follows: 1 = good, 2 = regular and 3 = bad.

The premise condition index (PCI) of the households where the scorpion stings occur could be a significant predictor of scorpion sting incidence. The socio-economic status of the population is another important factor to be considered in future studies, albeit it might be highly correlated with the premise conditions index and hence further work will be required to test this hypothesis.

In the studied region, antivenom serum is usually administered to 50% of the cases which are classified in moderate or severe state. The scorpion sting incidence formulas (3 and 4) predicts that for every 1°C increase in the minimum temperature, there will be an increase of 0.2 stings per month per 1000 people in Region 1 and 0.01 stings per month per 1000 people in Region 2. This result could be used to help determine the appropriate number of antivenom vials necessary for a specific region given appropriate climatological information.

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