Climatic factors and the occurrence of vesicular stomatitis in New Mexico, United States of America

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Summary
Vesicular stomatitis (VS) outbreaks occurred in the southwestern United States of America in 1995, 1997 and 1998. The epidemiology of VS is not understood completely and some of the epidemiologic aspects of this disease are currently under investigation. In this study, daily maximum temperature, daily minimum temperature, daily mean temperature, daily mean relative humidity and daily total precipitation were collected at the Sevilleta Long Term Ecological Research site in central New Mexico. Discriminant analysis was used to identify the climatic variables best able to classify in which months VS would occur. The study found that the amounts of precipitation occurring two, ten, eleven and twelve months prior to the month in which cases were diagnosed, were the climatic variables that best described the occurrence of VS cases. The association of VS cases and precipitation suggests that, like numerous other arthropod-borne diseases, transmission of the disease-causing pathogen is linked to variations in climate.

Keywords
Arbovirus – Climate – Discriminant analysis – Epidemiology – New Mexico – Precipitation – Vector – Vesicular stomatitis.

Introduction

Vesicular stomatitis (VS) in the United States of America (USA) is caused by either vesicular stomatitis virus, New Jersey serotype (VS-NJ), or vesicular stomatitis virus, Indiana serotype (VS-IN). These viruses are members of the family *Rhabdoviridae*, genus *Vesiculovirus*. Clinical VS is seen in cattle, swine and horses in the USA. However, serological evidence of virus exposure has been observed in many other species (7, 28). Reviews of the biologic, pathologic and epidemiologic aspects of this disease have been published (12, 14).

Two routine approaches to vesicular stomatitis virus infection diagnosis are available: antibody detection through a variety of serologic tests and virus detection through isolation. Detection of antibodies to VS viruses can be accomplished through application of the serum neutralisation test (SNT), the complement fixation test (CFT), and the enzyme-linked immunosorbent assays (ELISA). The SNT has been considered the standard serologic test for VS virus antibodies for many years. The OIE (World organisation for animal health) recognises the neutralisation test as a prescribed test for international trade. Samples with detectable antibody at greater than a 1:40 dilution are considered positive for international trade purposes. The CFT is also recognised as a prescribed test for international trade purposes and samples with titres greater than 1:5 are considered positive. Recently, the competitive enzyme-linked immunosorbent assay (cELISA) has become the serologic test of choice for screening purposes during outbreaks of VS in the USA. The cELISA is considered a prescribed test for international trade by the OIE, with a sample considered positive if the absorbance is greater than, or equal to, 50% of the absorbance of the diluent control.

Historically, outbreaks of VS in the southwestern USA are sporadic. Most recently, outbreaks have occurred in 1995, 1997 and 1998. Outbreaks typically begin in the late spring and end at the first frost. There is also typically a northward progression of disease through time, with the first positive premises in an outbreak identified in southern New Mexico and the last positive premises identified in Colorado. Recent outbreaks in the southwestern USA have resulted in clinical disease in greater proportions in horses than in cattle (14). In areas where VS is endemic (including Central America and Ossabaw Island, Georgia, USA) VS viruses are transmitted by arthropod vectors (2, 3). Arthropods apparently transmit VS viruses in the southwestern USA (15, 26).

The ecologic and epidemiologic factors associated with both the sporadic temporal and geographic nature of VS in nonendemic areas are poorly understood. Anecdotal reports of associations of VS outbreaks with certain climatic patterns, primarily above-average winter or spring precipitation, are not uncommon. Seasonality in disease occurrence suggests an association with specific weather conditions. Numerous arthropod-borne diseases are associated with climatic events, including dengue, malaria, St. Louis encephalitis and Ross River virus (10, 13, 22, 25). In the southwestern USA, Sin Nombre virus infections of humans have been linked to the effects of the El Niño Southern Oscillation (ENSO) on rodent populations (19, 20). The number of human plague cases in New Mexico was found to be associated with higher than normal winter-spring precipitation at a local level of measurement (21). A strong association between summer temperature and rainfall and seroconversion to bluetongue virus by cattle was found in Australia (27). It has been suggested that the spread of VS occurs through transport of virus-infected or virus-carrying vectors by winds during appropriate climatic conditions (24). Apart from this study, the authors are unaware of any other investigations of climatic factors and their potential association with outbreaks of VS in the southwestern USA. Our objective was to examine the effects of climatic factors on the incidence of VS outbreaks on premises in New Mexico. The relationship of local climate variables and outbreaks at state level were examined.

Materials and methods

Identification of positive premises

Information from the 1995, 1997 and 1998 VS outbreak databases was used for this study. A case in these outbreaks was defined as a facility that housed at least one animal, which was positive to one or more VS virus serologic tests, while concurrently exhibiting clinical signs consistent with VS and/or from which VS virus was isolated from submitted tissue or swab samples (1, 14). A four-fold increase in titre by CFT or SNT, obtained a minimum of seven days apart, was considered a positive serologic test for the index case in an individual state (14). For subsequent cases the detection of clinical signs and a positive result for a cELISA, clinical signs and a positive result for detection of antibodies by a CFT, or clinical signs and a four-fold increase in titre by CFT or SNT in paired sera obtained seven days apart, were necessary for an animal to be considered positive. Positive premises were not diffentiated by the species affected.

Climatic variables

Information on climatic variables was collected at the Sevilleta Long Term Ecological Research site (SLTER). The SLTER is located in Socorro County in central New Mexico and was established in October 1988. The SLTER is unique in that it straddles several major biomes of the southwest (8). The SLTER region is influenced by the ENSO, with major fluctuations in precipitation occurring on semidecadal time scales. Hourly readings of total precipitation, maximum temperature (MXT), minimum temperature (MIT), mean temperature (MNT), mean relative humidity (MNRH), mean vapour pressure, mean and maximum wind speed and daily solar radiation are collected at seven weather stations located within the SLTER. For this study, daily summaries of MXT, MIT, MNT, MNRH and total precipitation (PRECIP) were obtained from the SLTER for the years 1989 through 1999.

Descriptive statistics

Monthly mean values of MXT, MIT, MNT, MNRH and the total monthly precipitation were calculated. The average of each climatic variable for the eleven-year period (period average) was also calculated. The period average was used as a baseline to detect differences in climatic variables. Each climatic variable and its period average were plotted for each year by month. Climatic variables with large graphical displacements from the period average were examined in more detail by plotting the climatic variable by month for the year of a VS outbreak and the year prior to a VS outbreak along with the period average.

Multivariable analysis

A total of 132 months of data were available for analysis. A computer programme was used to produce a discrimination model through stepwise selection (a frequently applied method of achieving variable reduction) of continuous variables that proved useful in finding differences between classes. Two classes were established in this study: months in which VS cases were reported and confirmed (positive months) and months in which they were not reported (negative months). Variables entered the model if they were significant at the $p \leq 0.05$ level. Only those variables significant at $p \leq 0.10$ were retained in the model. The model considered all months in the years 1989 through 1999. For all climatic variables, lag period variables were created that represented months one to twelve prior to the monthly values calculated. Forward selection of variables into the discriminant model was conducted.

The significant variables identified in the discriminant model were entered into a computer programme to create classification tables. Proportional prior probabilities were assigned, due to the large number of months without any cases of VS. Error count estimates were also provided by this procedure.

Results

Simple plots of weather variables, by month for each year, showed only minor displacements from the eleven-year average for all variables except total monthly precipitation. Total monthly precipitation for the year of a VS outbreak and the year prior to a VS outbreak, along with the period average and number of VS cases, are presented in Figures 1 to 3.

Eight observations had missing data for one or more variables and were not included in the analysis. Overall, there were 17 positive months and 107 negative months.

A total of 65 climatic variables were available for modelling (Table I). The stepwise selection of variables into the model resulted in the twelve-, eleven-, ten- and two-month lag period variables of total monthly precipitation (L12PRECIP, L11PRECIP, L10PRECIP, L2PRECIP) remaining in the model (Table II).

The number and percentage of observations classified as either a positive or negative month are presented in Table III. Prior probabilities were 0.8629 for negative months and 0.1371 for positive months. The discriminate function incorrectly classified 3.74% of the negative months as positive (false positives) and 35.29% of the positive months as negative (false negatives).

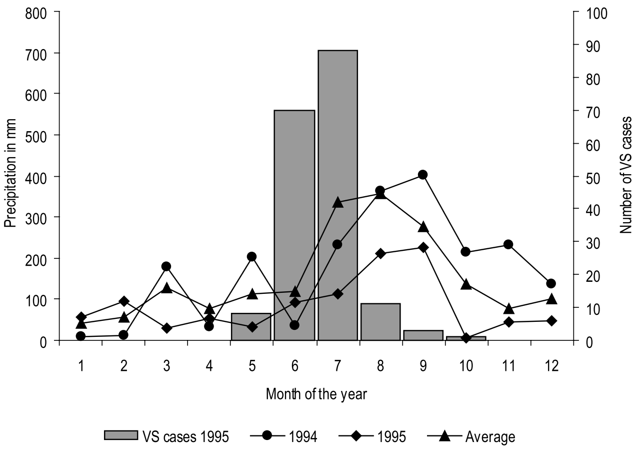

Fig. 1
Total monthly precipitation for 1994 and 1995, the eleven-year average monthly precipitation and the total number of vesicular stomatitis (VS) cases by month for 1995

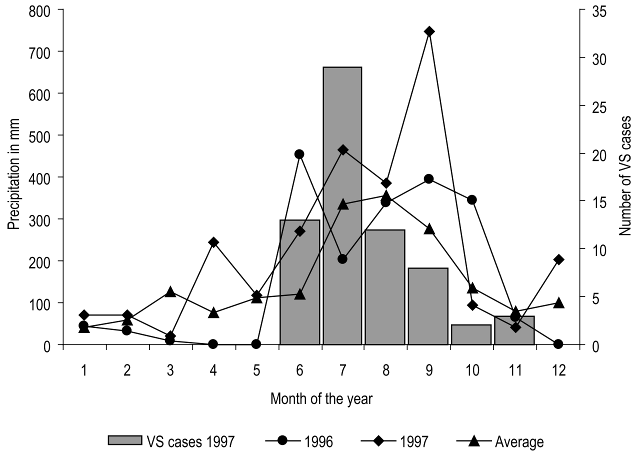

Fig. 2
Total monthly precipitation for 1996 and 1997, the eleven-year average monthly precipitation and the total number of vesicular stomatitis (VS) cases by month for 1997

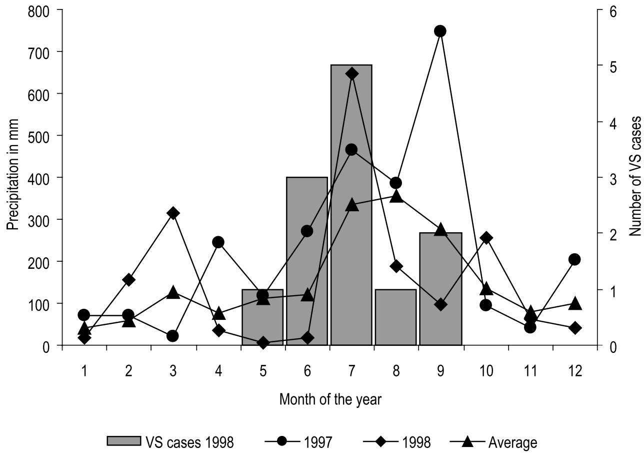

Fig. 3
Total monthly precipitation for 1997 and 1998, the eleven-year average monthly precipitation and the total number of vesicular stomatitis (VS) cases by month for 1998

Discussion

The lag period precipitation variables, identified as the best predictors, incorrectly classified only 10 months out of 124, for an overall error rate of 8%. Discriminant analysis indicated that ten- to twelve-month lag periods in total monthly precipitation and a two-month lag period in total monthly precipitation were significant predictors of in which months VS cases would occur. Examination of the graphical displays of precipitation,

Table I
Labels and descriptions of the variables included in the discriminant analysis which was used to identify the climatic variables best able to classify in which months vesicular stomatitis would occur

Variable name	Variable description
Maximum temperature (MXT)	Monthly mean value of daily maximum temperatures
Minimum temperature (MIT)	Monthly mean value of daily minimum temperatures
Mean temperature (MNT)	Monthly mean value of daily mean temperatures
Mean relative humidity (MNRH)	Monthly mean value of daily mean relative humidity
Total precipitation (PRECIP)	Total monthly precipitation
L1MXT to L12MXT	Monthly mean value of daily maximum temperatures 1 to 12 months prior to current month
L1MIT to L12MIT	Monthly mean value of daily minimum temperatures 1 to 12 months prior to current month
L1MNT to L12MNT	Monthly mean value of daily mean temperatures 1 to 12 months prior to current month
L1MNRH to L12MNRH	Monthly mean value of daily mean relative humidity 1 to 12 months prior to current month
L1PRECIP to L12PRECIP	Total monthly precipitation 1 to 12 months prior to current month

Table II
Results of stepwise selection of climatic variables that explain the differences in the incidence of vesicular stomatitis cases by month

Variable	Partial R-square	F value	Pr > F
L12PRECIP	0.1964	29.82	0.0001
L10PRECIP	0.0859	11.37	0.001
L11PRECIP	0.0481	6.07	0.0152
L2PRECIP	0.0390	4.83	0.0299

Significance level to stay in the model: $p < 0.10$

Table III
Number and percentage of observations classified as either months with vesicular stomatitis (VS) cases or months without VS cases

Type of month (positive or negative for VS)	Number of observations classified as negative (%)	Number of observations classified as positive (%)	Total
Negative months	103 (96.26)	4 (3.74)	107
Positive months	6 (35.29)	11 (64.71)	17
Total	109 (87.90)	15 (12.10)	124

that included the year prior to an outbreak, the year of an outbreak, and the eleven-year average, indicated that in all years prior to outbreak years there were multiple months that had above-average precipitation. In 1994 (Fig. 1), the year prior to the 1995 outbreak, six out of twelve months had above-average precipitation, with five out of those six months occurring in the ten- to twelve-month lag period. However, precipitation two months prior to the first month in which cases occurred in 1995 was below average and remained below average throughout the outbreak. In 1996 (Fig. 2), one year prior to the 1997 outbreak, only three out of twelve months had above-average precipitation, but all three occurred in the ten- to twelve-month lag period. Two months prior to the initial month in which cases occurred in 1997 precipitation was over 100 mm above average and remained above average in all months of the 1997 outbreak except the last two (October and November). In 1997 (Fig. 3), one year prior to the 1998 outbreak, nine out of twelve months had above-average precipitation and four out of the nine months were in the ten- to twelve-month lag period. Precipitation in the two months prior to the initial cases was approximately 200 mm above average. In each of the three outbreak years, the month with the highest total monthly precipitation occurred ten months prior to the peak number of cases. Above-average levels of precipitation may allow for increases in the reservoir and/or amplifying host populations that are necessary for VS outbreaks.

The role of precipitation variability in influencing levels of total biomass (both plant and animal) is well established. Large increases in rodent populations have been observed in response to the increased rainfall associated with El Niño events in the southwestern USA (6). These increases were shown to be associated with three- to six-month lag periods in precipitation. Rodent population increases have been correlated with precipitation increases in both the southwestern USA and South America (10, 13, 16). Rodent population increases have also been correlated with disease (11, 17).

A vertebrate reservoir of VS viruses has yet to be discovered, although numerous hosts have tested positive for antibodies to VS viruses. This list includes livestock species, birds and a host of small mammals including bats, deer mice, house mice, opossums, rabbits, raccoons, rock mice, skunks, squirrels, white-footed mice and wood rats. Viraemia has not been found in any field-collected potential reservoirs (12). Many arthropod-borne viruses have small mammals as either reservoir or amplifying hosts in their life cycles. It would not be unreasonable to assume that VS viruses also use a small mammal as their reservoir host.

Many vectors of arthropod-borne diseases have life cycles intimately dependent on water. Rain provides the breeding sites for many vectors and also helps to create a humid environment that assists in prolonging the life of vectors. The competency of some arthropods to serve as biological vectors of VS viruses in the southwestern USA has been demonstrated in laboratory settings. *Simulium* spp. (black flies) and *Culicoides* spp. (midges) can transmit VS viruses biologically (5, 15, 18). Members of these groups are abundant in the southwestern USA during VS outbreaks, have had VS virus isolated from field collections, and depend on aquatic systems for propagation (26). Black flies lay their eggs in water and, with rare exceptions, their larvae are filter-feeding organisms found strictly in running-water habitats (4). *Culicoides* spp. typically lay eggs in damp areas where there is decaying organic matter (9). The larvae of different *Culicoides* spp. can be found at the edges of ponds and streams or in areas around water troughs. Overwintering in the larval stage may occur in temperate climates.

Above-average precipitation during the vector season might provide larger numbers of potential breeding sites and therefore larger populations of arthropod vectors. Increased populations during a vector season may result in more larvae overwintering. This would result in larger initial insect populations during the transmission season of the following year. A large initial hatch of arthropods may be the trigger necessary to begin transmission of the virus, if it is present. If the virus persists in only a small number of reservoirs, arthropod vectors may be necessary to move the virus into larger numbers of reservoirs and amplifying hosts or act as the amplifying hosts themselves, resulting in a spillover of the virus into livestock species. The virus might survive in the southwestern USA through the winter months. Five virus isolates obtained in New Mexico in the spring of 1997 and in the summer of 1998 were identical to two virus isolates obtained in Colorado in 1997. This indicated that the same VS-IN virus caused outbreaks in the spring and summer of 1997 and 1998 (23). No specific evidence exists to indicate that VS viruses over-winter in arthropods. However, without the identification of a vertebrate species that exhibits viraemia, the over-wintering of VS virus in arthropods is plausible.

The limitations of this study are important to note. The model used accurate and specific climatic information but from a limited geographic area. A major point of a recent paper on plague incidence and its relationship to precipitation was that local climate effects are the best predictors of disease occurrence. In the study reported here, we used climate data from seven weather stations located on the SLTER. Cases of VS between 1989 and 1999 occurred from southern New Mexico, near the Texas border, to northern New Mexico, near the Colorado border. Climate is generally similar across New Mexico, but local differences do occur and should be considered.

It is unlikely that all cases of VS are either detected or reported. Therefore, the dependent variable in the model is underestimated. It is reasonable to assume that undetected or unreported cases occur in the months observed in these data sets. Recent work conducted by this research team has found evidence to support that vesicular stomatitis virus infections may be occurring in non outbreak years (B.J. McCluskey, unpublished data, 2003). This would have a significant effect on the association of lag period precipitation and when cases occur.

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Influence des facteurs climatiques sur l'apparition de la stomatite vésiculeuse dans l'État du Nouveau-Mexique (États-Unis d'Amérique)

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Résumé

Plusieurs foyers de stomatite vésiculeuse ont été dépistés aux États-Unis d'Amérique en 1995, 1997 et 1998. Divers aspects de l'épidémiologie de la maladie font actuellement l'objet de recherches en vue de compléter des connaissances encore fragmentaires en la matière. Dans le cadre de cette étude, la température diurne minimale et maximale, la température diurne moyenne, l'humidité relative moyenne et les précipitations totales ont été relevées quotidiennement sur le site de la station de recherches écologiques à long terme de Sevilleta, dans le centre du Nouveau-Mexique. L'analyse discriminante a permis de trouver les variables climatiques les plus adéquates pour le classement des mois de l'année selon les probabilités d'apparition de la stomatite vésiculeuse. L'étude a montré que la pluviométrie enregistrée deux, dix, onze et douze mois avant le dépistage des cas était la variable climatique la plus fiable pour déterminer le moment d'apparition de la stomatite vésiculeuse. La mise en parallèle des cas de stomatite vésiculeuse et des précipitations donne à penser que la transmission de l'agent pathogène est tributaire des variations climatiques, à l'instar de nombreuses autres maladies transmises par les arthropodes.

Mots-clés

Analyse discriminante – Arbovirus – Climat – Épidémiologie – Nouveau-Mexique – Précipitation – Stomatite vésiculeuse – Vecteur.

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Factores climáticos y aparición de estomatitis vesicular en Nuevo México (Estados Unidos de América)

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Resumen

En 1995, 1997 y 1998 se produjeron brotes de estomatitis vesicular en el sudoeste de los Estados Unidos de América. Todavía no se entiende completamente la epidemiología de esa enfermedad, algunos de cuyos aspectos epidemiológicos se están investigando actualmente. En el estudio descrito por los autores, se recogieron una serie de datos en las instalaciones de investigación ecológica a largo plazo de Sevilleta, situadas en el centro de Nuevo México, para después calcular los siguientes parámetros: temperatura máxima, mínima y media diarias, humedad relativa media diaria y precipitación total diaria. Después se utilizó un análisis discriminante para determinar las variables climáticas idóneas para clasificar en función de ellas los meses en que iba a manifestarse la estomatitis vesicular. El estudio puso de relieve que el volumen de precipitaciones en los meses segundo, décimo, undécimo y duodécimo antes del mes en que se habían diagnosticado los casos era la variable climática que mejor describía la aparición de la estomatitis vesicular. La relación entre esa enfermedad y la precipitación lleva a pensar que, al igual que en otras muchas afecciones vehiculadas por artrópodos, la transmisión del agente etiológico está ligada a variaciones en el clima.

Palabras clave
Análisis discriminante – Arbovirus – Clima – Epidemiología – Estomatitis vesicular – Nuevo México – Precipitación – Vector.

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