St. Louis Encephalitis

Background Information

General

St. Louis Encephalitis (SLE) was first discovered in St. Louis, Missouri in 1933. Several epidemics of the disease have occurred since its discovery, including more recent outbreaks in 1990 in Florida and Texas (dhpe.org). Most SLE cases in the United States have occurred in the eastern and central states, including episodic urban outbreaks. In the rural western states, however, the pattern of transmission has been much more endemic (cdc.gov).

Everyone is susceptible to SLE who is resident of or visitor to areas where the virus is actively transmitted. People who engage in outdoor work and activities are especially at risk, as are those living in low-income areas (cdc.gov).

There is no treatment for SLE. Potentially infected persons should visit a healthcare provider to receive treatment for their symptoms. Prevention, however, is possible with SLE. Because the disease is transmitted through a vector (mosquitoes), the primary method of prevention includes avoiding mosquito bites. This can be accomplished by applying an insect repellent containing diethyl-meta-toluamide (DEET), picaridin, IR3535 or oil of lemon eucalyptus to exposed skin and/or clothing. Wearing long sleeves and pants, having secure screens on windows and doors, and eliminating prime mosquito breeding sites (including standing water) are also effective methods of prevention (cdc.gov).

This disease is important to study because it can cause encephalitis, a potentially deadly condition. Encephalitis is an inflammation of the brain. This swelling can affect motor skills and, if not quickly treated, can lead to permanent brain damage and death (encephalitis.ifas).

Mosquitoes

A mosquito becomes infected with SLE by biting an infected bird (usually a house finch or house sparrow) (cdc.gov). Once infected, the mosquito remains infected for the entirety of its life (encephalitis.ifas). The mosquito's lifetime is only approximately two to three weeks (Conlon).

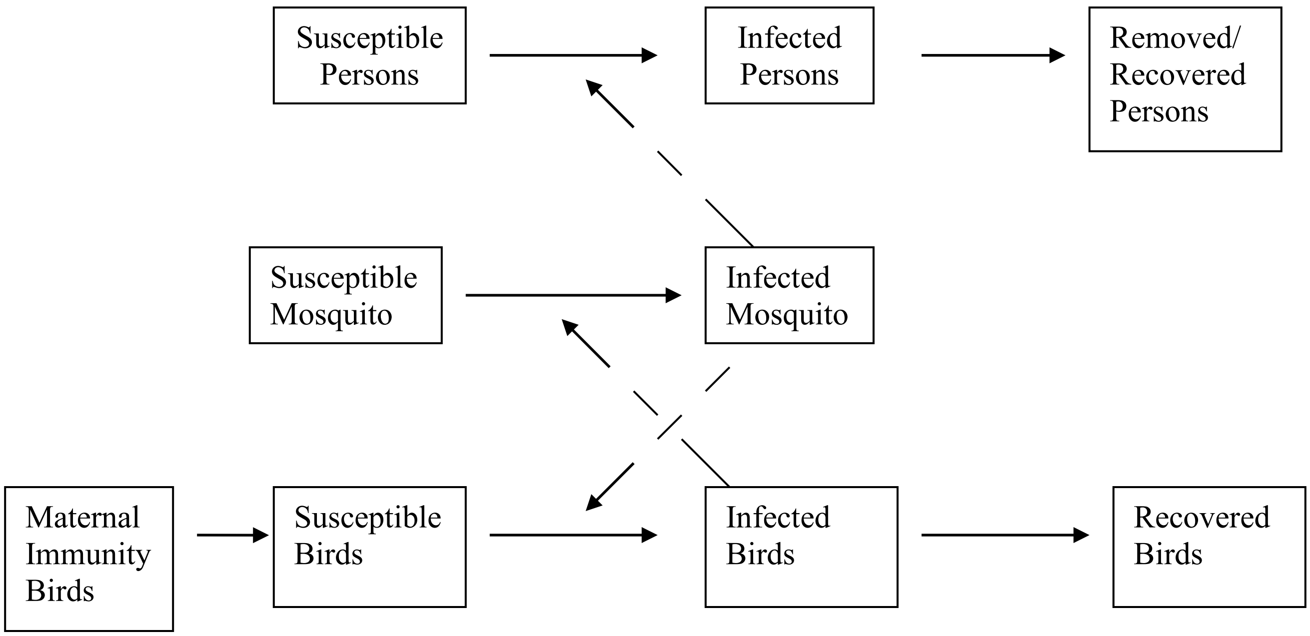
Birds

A mosquito infects a bird when it bites the bird (cdc.gov). Once a bird is infected, it remains infectious for one or two days, and the virus has completely disappeared after two or three days (encephalitis.ifas). After recovering, birds are immune from the disease for life (Fang, Reisen). While infected, birds do not show any symptoms (encephalitis.ifas). Maternal immunity to SLE is also possible. Doves have a maximum maternal immunity of 16 weeks, while chickens' maternal immunity lasts only 12 weeks (Sturgeon, French, Brookman). One could reasonably assume that the maternal immunity of finches and/or sparrows is approximately 16 weeks because they are similar in size to doves.

Humans

A mosquito infects a human by biting the person (cdc.gov). Once infected, a human's incubation period is 5-15 days, after which the person will potentially begin to show symptoms. While there is a delay prior to the display of symptoms, we are assuming that a human becomes infectious at the same time that he/she becomes infected. The severity of SLE, including prevalence and manifestation of symptoms, are strongly correlated with age. Persons over 60 years of age are approximately 5 to 40 times more likely to show symptoms than persons under 10 years of age. In persons under the age of 50, mortality is less than 5%; in people over 50, it increases to somewhere between 7 and 25% (encephalitis.ifas). Symptoms can last from a few days to several weeks, and neurological effects may be permanent (westnil.stat.pa). Symptoms include fever, headache, dizziness, and nausea. Symptoms intensify near the beginning of the disease. After this period, some patients spontaneously recover while others develop signs of central nervous system infections. These central nervous system infection symptoms include stiff neck, confusion, disorientation, dizziness, tremors, and unsteadiness; in more severe cases, coma and/or death may result (cdc.gov). While development of the actual encephalitis condition is rarer in children and young adults, it is found in almost 90% of the elderly people infected with SLE (cdc.gov).

The SIR model of St. Louis Encephalitis



$$\Delta S_p = \mu N_p - \nu S_p - \alpha S_p I_m$$
$$\Delta I_p = \alpha S_p I_m - \nu I_p - \gamma I_p - \xi I_p$$
$$\Delta R_p = \gamma I_p - \nu R_p$$
$$\Delta S_m = \delta N_m - \beta S_m I_b - \sigma S_m$$
$$\Delta I_m = \beta S_m I_b - \sigma I_m$$
$$\Delta M_b = \varepsilon \kappa N_b - \tau M_b - \eta M_b$$
$$\Delta S_b = \varepsilon (1-\kappa) N_b - \eta S_b - \lambda S_b I_m + \tau M_b$$
$$\Delta I_b = \lambda S_b I_m - \eta I_b - \varphi I_b$$
$$\Delta R_b = \varphi I_b - \eta R_b$$

Where,
S_p is the number of susceptible persons

μ is the natural birth rate of persons
N_p is the population of persons
ν is the natural death rate of persons
α is the transmission rate from infected mosquitoes to susceptible persons
I_m is the number of infected mosquitoes
I_p is the number of infected persons
γ is the recovery rate of persons
ξ is the death rate from SLE of persons
R_p is the number of recovered persons
S_m is the number of susceptible mosquitoes
δ is the birth rate of mosquitoes
N_m is the population of mosquitoes
β is the transmission rate from infected birds to susceptible mosquitoes
I_b is the number of infected birds
σ is the natural death rate of mosquitoes
I_m is the number of infected mosquitoes
M_b is the number of birds with maternal immunity
ε is the natural birth rate for birds
κ is the proportion of birds born with maternal immunity
N_b is the population of birds
τ is the rate of movement from maternal immunity to susceptible for birds
η is the natural death rate for birds
S_b is the number of susceptible birds
λ is the transmission rate from infected mosquitoes to susceptible birds
I_b is the number of infected birds
φ is the recovery rate for birds
R_b is the number of recovered birds

SIR Model Assumptions:

- Once a mosquito is infected, the mosquito remains infected for life.
- A mosquito becomes infected by biting an infectious bird.
- Some birds are born with maternal immunity.
- A bird becomes infected by being bitten by an infected mosquito.
- Once a bird recovers, the bird has immunity for life.
- A person becomes infected by being bitten by an infected mosquito.

- Once a person recovers, the person has immunity for life.

Method

We found data on the number of occurrences of SLE in Texas from 1972 to 1991 (at cdc.gov). We attempted to find logical variables to create a multiple linear regression model that would predict when the number of cases of SLE in Texas would occur; the intent was to be able to use this model for extrapolation purposes to potentially predict further epidemics of the disease. We input the data into SPSS and ran various linear regression models after creating scatter plots in an attempt to determine how related each factor was to the number of actual cases of SLE. We attempted to choose variables that we thought would be relevant to mosquito production, and the general transmission of the disease. We found data for the following predictor variables:

- Air temperature (weatherexplained.com)
- Water temperature (usgs.gov)
- Texas population (census.gov)
- House Sparrow population (usgs.gov)
- House Finch population (usgs.gov)
- Annual precipitation (weatherexplained.com)

We would have liked to use the variable of dew point, but we were unable to find data. We would also have liked to have used the variable of water table levels, but we were unable to find data for this as well. We chose variables that related to the transmission of the disease to the best of our knowledge. Mosquito population size is dependent on climate, which involves air and water temperature as well as precipitation; mosquitoes lay their eggs in the water and they have optimal air temperature living environments. Since the disease is transmitted between birds and mosquitoes, a reasonable assumption is that the bird population would affect the transmission of the disease. We gathered the data about the Texas population under the assumption that if there are more people, then there will be more infections. However, this is data over time; as time has progressed so have our defenses against mosquitoes such as screens, better living conditions, and more knowledge of SLE.

Results and Discussion

Our best model involved the variables of air temperature and water temperature. The equation is

$$\begin{aligned} \textit{number of cases} \\ &= 27.1 - .694\ \textit{water temp} - 9.8\ \textit{air temp stand} \\ &+ 18.4\ \textit{air temp stand sq} + 13.8\ \textit{air temp stand cub} \end{aligned}$$

Squaring air temperature and cubing air temperature yielded the model with the best fit. Air temperature was standardized to reduce a multicollinearity issue (explained below). This model gave us the lowest p-value of .058 and the largest R^2 of .436. All other variables were not significant with p-values larger than .15. Usually, variables are deemed not significant if the p-value is larger than .05. However, if we used this standard, we would have no significant variables. Also, the p-value = .05 is generally used with more controlled situations and/or with data that is more certain, i.e. the data is gathered with a small amount of uncertainty regarding the accumulated values.

Some other regression models examined:

- A model including solely annual precipitation vs. number of cases yields a p-value of .7. The R^2 value is .008. This is a poor linear relationship. See Figure 3.
- A model including solely air temperature vs. number of cases yields a p-value of .234. The R^2 value is .078. This is a fairly poor linear relationship. A cubic relationship fit much better. The R^2 value for a cubic relationship was .349, which is a sufficiently good fit. See Figure 4.
- A model including solely water temperature vs. number of cases yields a p-value of .171; this is the model with the lowest p-value for a single variable. Thus, if you had to choose a single "best" variable to put in the model, it would be water temperature. The R^2 .101. This is a fair linear relationship. See Figure 5.
- A model including solely the House Finch Texas population vs. number of cases yields a p-value of .97. The R^2 value is .00008108. This is an extremely poor linear relationship. See Figure 6.
- A model including solely the House Sparrow Texas vs. number of cases population yields a p-value of .772. The R^2 value is .005. This is a poor linear relationship. See Figure 7.
- A model including solely the human Texas population vs. number of cases yields a p-value of .718. The R^2 value is .007. This is a poor linear relationship. While one might expect that as the human population goes up, there are more people to infect, and so number of cases will increase, this was not true. It must

be noted that the human population increases over time. Concurrently increasing over time are factors such as awareness of the disease, precautions such as screens on windows, and technological developments such as DEET in insect repellents. See Figure 8.

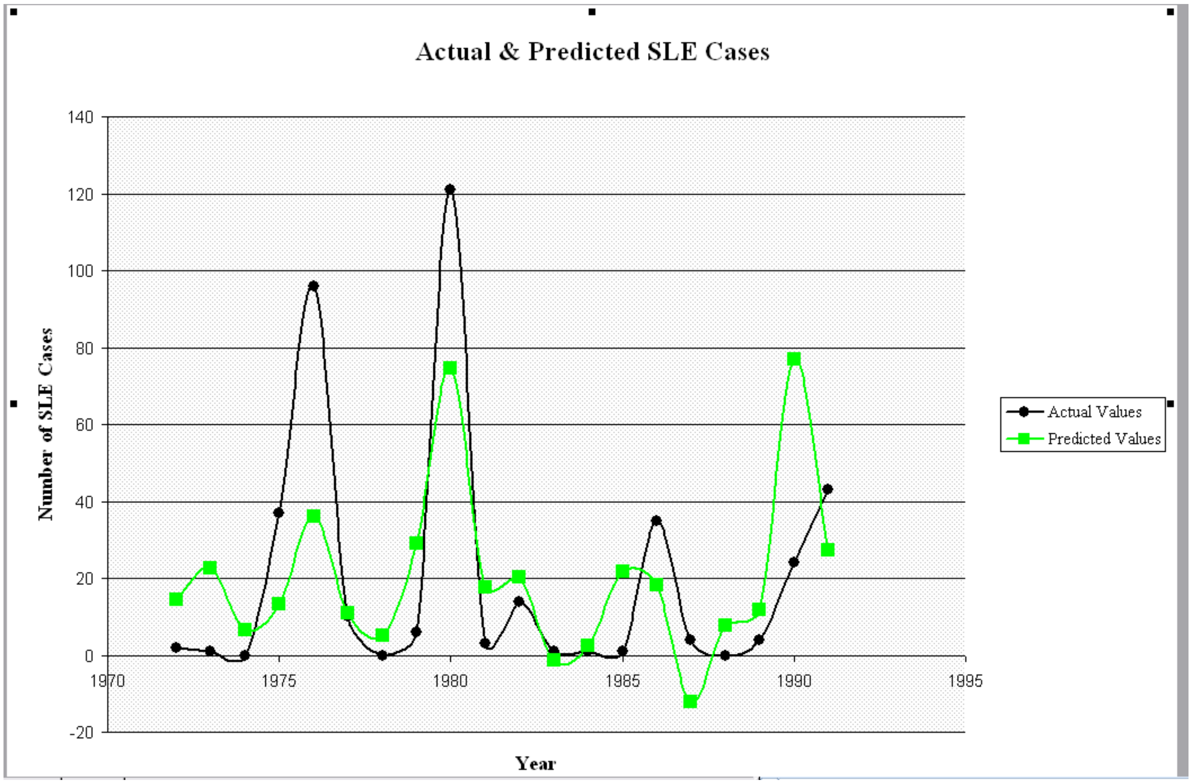
The above models are those involving only one variable. This is just an example of some of the models we ran. We also ran models using multiple variables and transforming some variables (as indicated by our final model). The method used to determine the final model was that of backward elimination. Relatively simple linear regression models were ran using annual precipitation, precipitation squared, and precipitation cubed to see if the polynomial factor would help at all. The same was done for air temperature and water temperature. The precipitation and water temperature models were not improved by the polynomial changes, so those adjustments were removed. Air temperature was included since polynomial adjustments did improve the model. The model then started with annual precipitation, the air temperature variables (air temperature, air temperature squared, and air temperature cubed), water temperature, sparrow, finch, and human populations. Variables were eliminated until all variables left in the model were within the significance of .15. The last variable eliminated was that of annual precipitation, so one could say that of the insignificant variables, annual precipitation is the most significant.

In running this backward elimination, we discovered that it was necessary to standardize (take each value and subtract off the total mean) air temperature, because the multicollinearity between air temperature and its polynomial variables was extraordinarily high (on the order of 523,000,000; values greater than 10 are an issue). Standardizing air temperature (and calculating its polynomial variables from the standardized values) allowed all variables to remain in the final model.

The following is our best model predictions compared to the actual data of Texas cases in Excel format.

Number of SLE Cases	Predicted Number of SLE Cases
2	14.3662
1	22.5356
0	6.4576
37	13.2828
96	36.1989
10	11.0513
0	5.0245
6	29.1562
121	74.6531
3	17.7507
14	20.3084
1	-1.2582
1	2.6154
1	21.8763
35	18.1856
4	-12.1885
0	7.6122
4	11.8466
24	76.8322
43	27.1636

The following is a graph that depicts the actual and predicted values over time.



By examining the above table and graph one can see that the model we created predicted peaks of SLE cases relatively well such as in the years 1976, 1980, and 1986. The model over-predicted the number of cases in the year 1990 and under-predicted in 1987. Though in both of these cases, the predicted number of cases moving the direction of the actual number of cases. Qualitatively one can see in the graph that the predicted line moves up and down fairly well compared to the actual line.

In conclusion, we are surprised by the quality of the outcome. We were not expecting a model that would predict the number of cases so well. However, we are sure there is a better model out there; possibly, a model that contains other climate variables such as dew point and possibly some interaction variables.

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Appendix:

Figure 1: The number of SLE cases in Texas

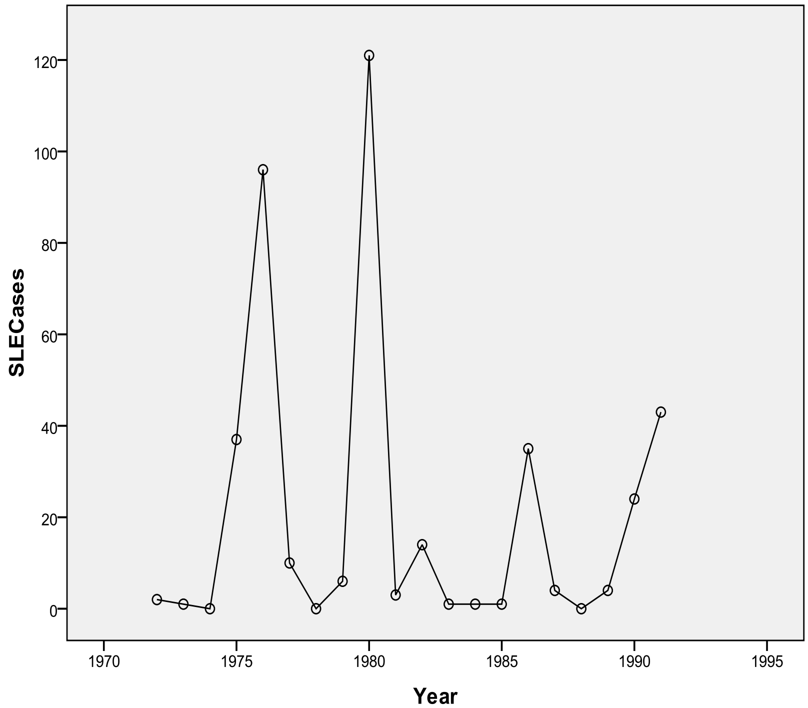

Figure 2: The number of SLE cases in Texas (note the outliers: epidemics in the years 1976 and 1980)

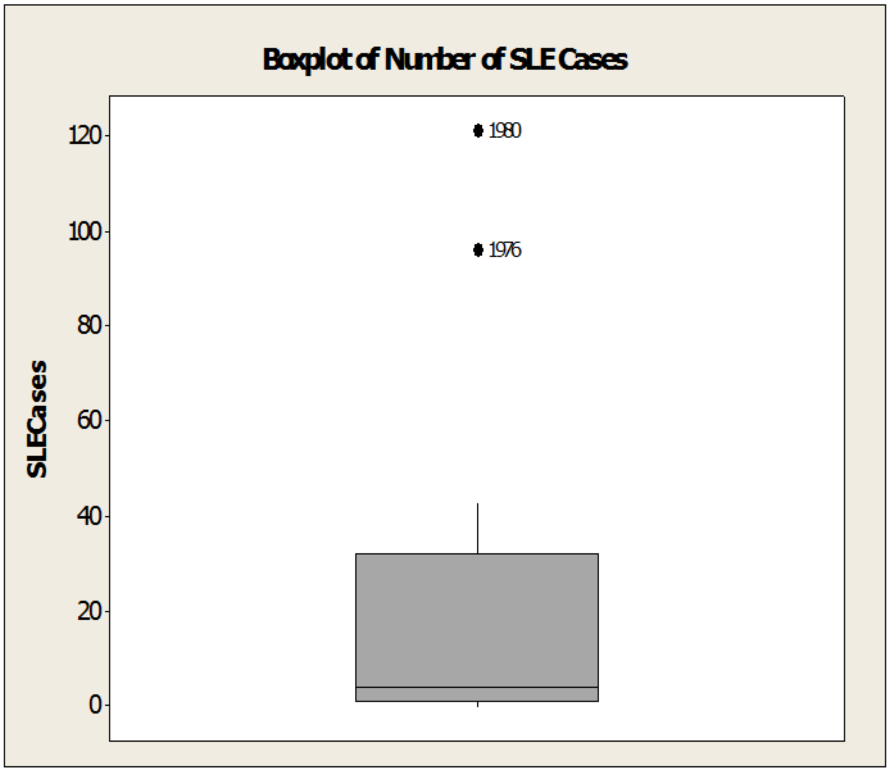

Figure 3: Number of SLE cases vs. annual precipitation (in inches)

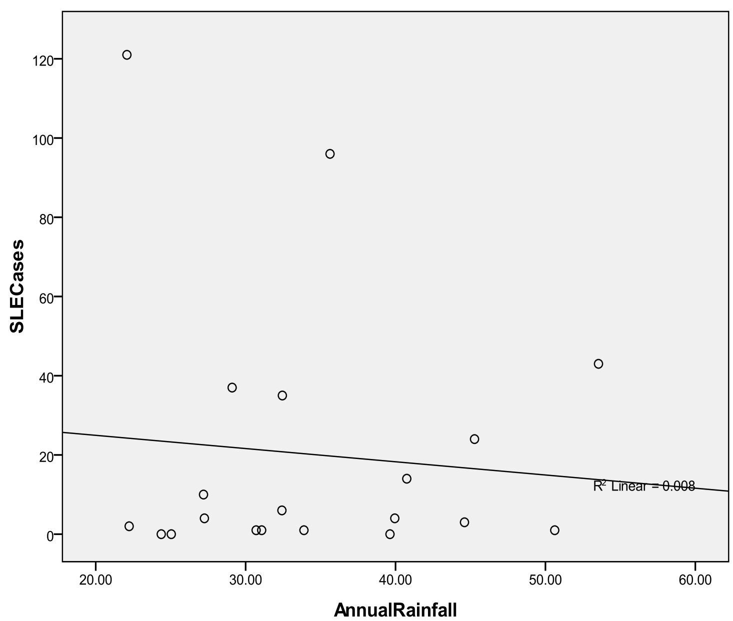

Figure 4: Number of SLE cases vs. air temperature (in degrees Fahrenheit)

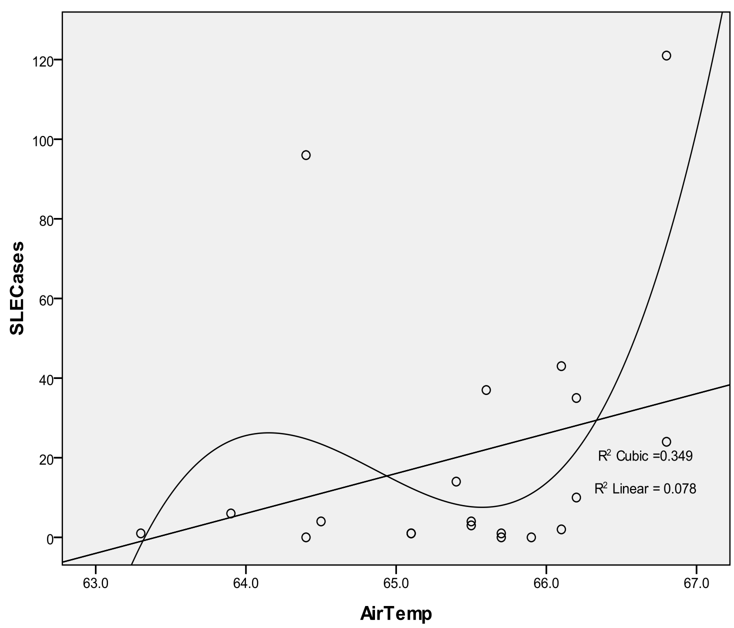

Figure 5: Number of SLE cases vs. water temperature (in degrees Celsius)

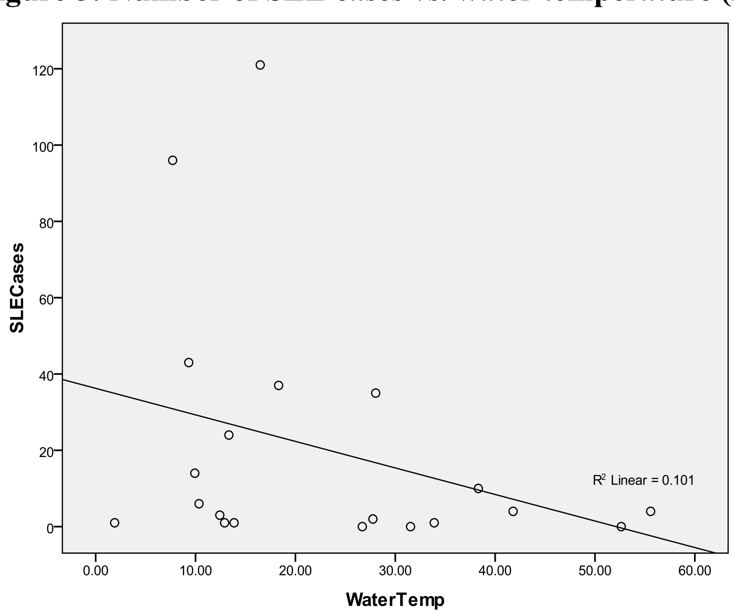

Figure 6: Number of SLE cases vs. finch population

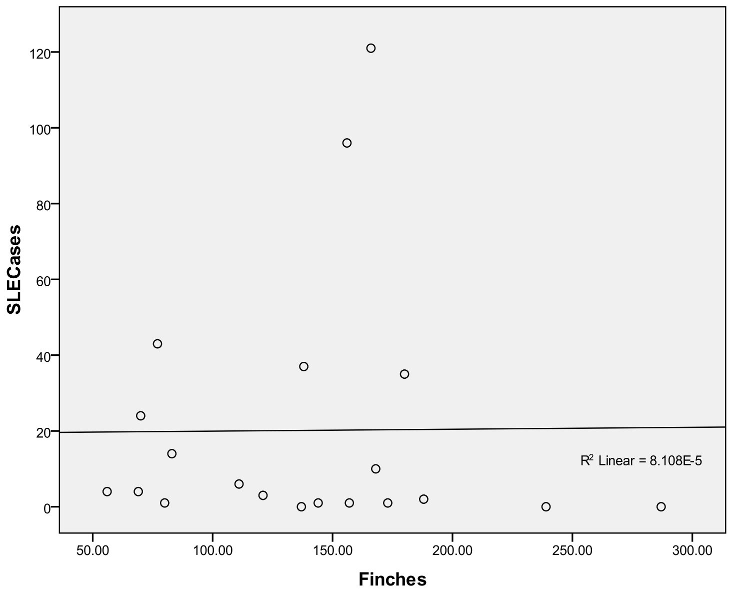

Figure 7: Number of SLE cases vs. sparrow population

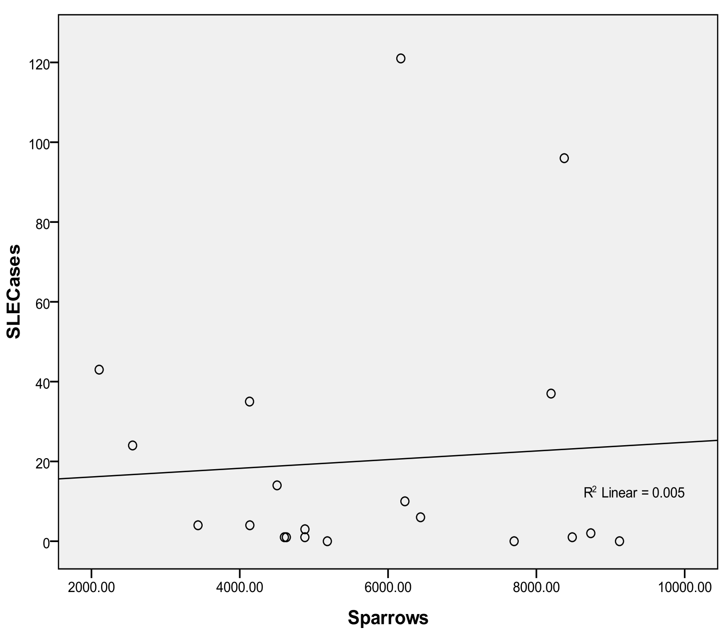

Figure 8: Number of SLE cases vs. human population of Texas

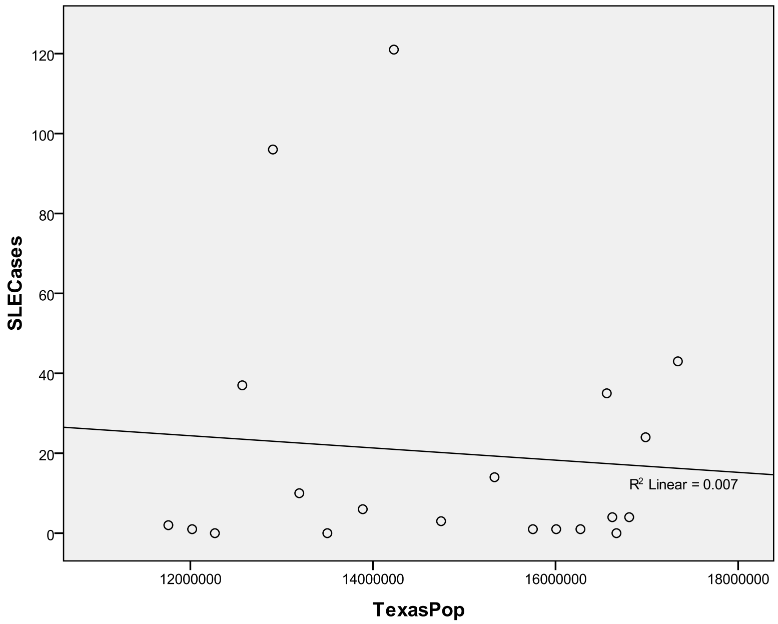

Figure 9: The data used for calculating the predicted values

Year	Air Temperature	Water Temperature	Air Temperature Standardized	Temperature^2 Standardized	AirTemperature^3 Standardized	Number of SLE Cases	Predicted Number of SLE Cases
1972	66.1	27.76	0.69	0.4761	0.328509	2	14.3662
1973	65.1	12.91	-0.31	0.0961	-0.029791	1	22.5356
1974	65.9	31.53	0.49	0.2401	0.117649	0	6.4576
1975	65.6	18.32	0.19	0.0361	0.006859	37	13.2828
1976	64.4	7.71	-1.01	1.0201	-1.030301	96	36.1989
1977	66.2	38.32	0.79	0.6241	0.493039	10	11.0513
1978	64.4	52.63	-1.01	1.0201	-1.030301	0	5.0245
1979	63.9	10.35	-1.51	2.2801	-3.442951	6	29.1562
1980	66.8	16.48	1.39	1.9321	2.685619	121	74.6531
1981	65.5	12.43	0.09	0.0081	0.000729	3	17.7507
1982	65.4	9.93	-0.01	1E-04	-1E-06	14	20.3084
1983	63.3	1.9	-2.11	4.4521	-9.393931	1	-1.2582
1984	65.7	33.9	0.29	0.0841	0.024389	1	2.6154
1985	65.1	13.86	-0.31	0.0961	-0.029791	1	21.8763
1986	66.2	28.04	0.79	0.6241	0.493039	35	18.1856
1987	65.5	55.57	0.09	0.0081	0.000729	4	-12.1885
1988	65.7	26.7	0.29	0.0841	0.024389	0	7.6122
1989	64.5	41.8	-0.91	0.8281	-0.753571	4	11.8466
1990	66.8	13.34	1.39	1.9321	2.685619	24	76.8322
1991	66.1	9.32	0.69	0.4761	0.328509	43	27.1636
average air temp:	65.41						