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Date

The Association between ambient temperature and snakebites in Georgia

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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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Abstract

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Abstract

There is a dearth of epidemiologic research on environmental risk factors for snakebites both internationally and domestically. The World Health Organization has identified snakebites as a highest priority neglected tropical disease. In this study, we use data from the Georgia Hospital Association from January 1, 2014 to December 31, 2018 combined with zip code level climate data to analyze the relationship between short-term temperature variation and Emergency Department visits for snakebite. To do this, we performed a case-crossover analysis using conditional logistic regression modeling. We used a time stratified, bi-directional approach where control days were chosen as the same day of the week within the same month and year. With adjustment for dew point and precipitation, we found that across the entire study period, temperature is significantly and positively associated with the snakebite outcome (OR 1.064, CI 1.044 -1.084). Seasonal stratification showed that the association is strongest in the spring (OR 1.106, CI 1.070 -1.144) followed by fall (OR 1.065, CI 1.032 - 1.100). In winter and summer, temperature variation was not significantly ($P>0.05$) predictive of the snakebite outcome. Our results supported our hypothesis that short-term variation in temperature would be a significant predictor for the odds of experiencing a snakebite, and that the effect would be strongest at moderate temperatures. Because snakebites occurred most frequently in the summer, we speculate that there may be human behaviors that we did not analyze which contribute towards higher snakebite counts in Georgia summers.

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Table of Contents

Introduction

Snakes are beautiful and enigmatic creatures. Also enigmatic are epidemiologic data describing the burden of snakebites. An estimated 5.4 million snakebite events occur globally each year (WHO 2019). The WHO has identified snakebite envenomation as a highest priority neglected tropical disease with inadequate epidemiological reporting (WHO 2018). Broadly speaking, there are three types of snakebite. The first are bites where a venomous snake envenomates the victim. Poor outcomes related to these events are often preventable with proper treatment, but untreated can progress to serious irreversible damage including permanent limb dysfunction or death (Ahmed 2008). In more serious cases, death may result through respiratory failure (elapid species) or hemorrhagic shock (viper species) (Langley et al 2020) (Ahmed 2008). Second are “dry bites” from venomous species. And third are bites from non-venomous species. The latter two cases are generally not medically dangerous, but patients may seek care out of caution.

In the US specifically, around 9,000 individuals a year seek medical attention for snakebites in emergency departments (Langley 2020). Fortunately, mortality is low with an average of only six deaths per year reported between 2001 and 2015 (Lavonas et al 2011, Langley 2020). Although snakebite morbidity and mortality are low, these events can still have powerful impacts on an individual’s life through medical complications, allergic reaction to antivenom, or high cost of care (Rodriguez 2019) (Gold 2004).

In addition to the health impacts, treatment for snakebites creates an economic burden for patients. The World Health Organization has described cost of care as a serious consequence of snakebite events (WHO 2018). In recent years, the supply and demand economics for antivenom worldwide have become unstable. In the US, high costs and inconsistent availability of antivenom are a function of monopoly and market failure in which low demand raises costs and further lowers demand. One product, Crofab (BTG International), has dominated the pit viper anti-venom market in the US since 2000 (Rodriguez 2019) (Wade 2014) (Battle of the Antivenoms 2020). The comparable product for elapid species, NACSAV (Phizer), is no longer produced due to low demand McGhee 2020) (Hessel and McAnich 2020) (Yang et al 2017). The medical community has shifted treatment recommendation for Elapids to anticholinergics due to unreliable antivenom availability (McGhee 2020) (Hessel and McAnich 2020). A cost analysis reported that the comparable antivenom vial that is billed at 7,000-39,000$ in the US retails for 100$ in Mexico (Boyer 2015). This difference in price was largely attributed to negotiations between hospitals and contracted payers (Boyer 2015). The high cost of hospitalization and treatment with anti-venom, adds insult to injury in an already anxiety-inducing experience for American patients (Rodriguez 2019).

The southeastern region of the United States is of particular interest regarding risk for snakebites. Our study takes place in Georgia, a southeastern state. An analysis using the CDC Wonder database between 1997 and 2007 reported that 38 of 53 (~70%) reported fatalities attributable to ‘Venomous Snakes and Lizards’ occurred in the South (Forrester et al 2007). A second study using the same data set for 1999-2017 found that Georgia was the second leading state in snakebite deaths (thirteen deaths), a close second to California (fourteen deaths), despite its much smaller population (Langley et al 2020). The Georgia Poison Control Center reported two snake related deaths between 2014 and 2020 (GA PCC Summary Statistics).

Climatic variables, primarily heat and humidity, are known to be associated with snake activity (Chippaux 2017). This study investigates the association between hospital visits for snakebite and ambient temperature in Georgia. Georgia is one the most biodiverse states in herpetofauna, and particularly snakes (Stevenson 2017) (Jensen et al 2008). There are forty-six snake species in Georgia, six of which are venomous and of concern to humans (Georgia Poison Center 2020). An additional twelve are technically venomous but not at a medically meaningful level (Wilson 2020). Of the six venomous species, five belong to the Crotalidae Pit Viper family, including: Eastern Copperhead *A. contortrix*, Northern Cottonmouth *A. piscivorus*, Eastern Diamond-backed Rattlesnake *Crotalus adamanteus*, Timber Rattlesnake *Crotalus horridus*, and the Pigmy Rattlesnake *Sistrurus miliarius* (Savannah River Ecology Laboratory). One Georgian venomous species belongs to the Elapid family, the Eastern Coral Snake *Micrurus fulvius* (Savannah River Ecology Laboratory). On the following page, find photographs of four of the most prominent venomous species of Georgia. All photos were provided courtesy of Dr. Larry Wilson (Emory Environmental Sciences).

1) Copperhead

2)Cottonmouth

3) Eastern Diamondback Rattlesnake.

4)Eastern Coral Snake

All above photos were taken by Larry Wilson, Emory Environmental Sciences

In Georgia, snakes brumate – a physiologic state in reptiles comparable to hibernation in mammals – in cold-weather seasons (Jensen et al 2008) Snakes enter this dormancy period when external temperatures become too cold to maintain proper core body temperature. As a response, snakes reduce physiologic processes to prioritize thermoregulation (Jensen et al 2008). Brumation is a more flexible process than hibernation in that snakes may “awaken” from dormancy as a response to short-term changes in temperature (Roman 2018). In the southeast, snakes engage primarily in brumation but may also engage in its contrasting behavior known as estivation. Estivation is a dormancy response of prolonged hot, dry periods (Jensen et al 2008). As a result of the known impact that temperature has on snake activity, and these season-specific behaviors, we hypothesize that short-term variation in temperature will be a significant predictor for the odds of experiencing a snakebite, and that the effect will be strongest at moderate temperatures.

Methods

We conducted a case-crossover study to explore the relationship between ambient temperature and emergency department visits for snakebite, as described below.

Health data

The hospital data comes from the Georgia Hospital Association. It includes all emergency department visits between the years 2014-2018. The data includes date of event, the ICD code for the reason for the visit, and the home zip code of the patient. Patients with missing zip codes or non-Georgia zip codes were excluded from the study.

Three ICD codes relating to snake encounters were chosen for analysis as outcomes of interest (Table 1). The transition from ICD 9 to ICD 10 occurred during the study period, in the year 2015. As such, ICD-9 codes were used for outcome identification for the first year of the study, while ICD-10 codes were used for the remaining four years (Table 1). A fourth ICD code, ‘toxic effect venom’, was used to compare against snake-specific outcomes. This code includes encounters with snakes and other reptiles such as scorpions, arthropods, venomous fish, marine animals, venomous plants, and unspecified venomous animals. For our analysis, we subtracted snake-specific outcomes from ‘Toxic Effect Venom’ to define that outcome as not including snakebite events.

Table 1) ICD Code Definitions

ICD Edition	Venomous Snakebite	Non-Venomous Snakebite	Toxic Effect Venom	Any Snakebite
ICD-9	E905.0	E906.2	989.5	E905.0, E906.2
ICD-10	T63.0	W59.1	T63 – (Any Snakebite)	T63.0, W59.1

Exposure data

The exposure of interest was the same-day maximum daily temperature in the zip code of residence. In sensitivity analysis, we also looked at minimum temperature, a one day lag of temperature, and an average between the same-day and the one day lag (see appendix). Precipitation and dew point data were included as potential confounders, as they are also known to influence snake behavior (Goldstein et al 2021, Chaves et al 2015, Angarita-Gerlein 2017, Ediweera et al 2018, Hansson et al 2009). All meteorological data was collected from Daymet. Daymet is a NASA supported project of Oak Ridge National Laboratory. Algorithms are used to produce daily meteorologic parameters at the resolution of a 1 km by 1 km gridded surface (Thornton et al 1997) (https://daymet.ornl.gov/).

Statistical analysis

A case crossover study design with conditional logistic regression was used for analysis. In this design, each subject serves as their own control. For selection of control days, we used a time stratified, bi-directional approach where the control days were chosen as the same day of the week within the same month and year, leading to 3-4 control days per case. As a result, the specific control definition naturally accounts for time-trends such as seasonality, long-term trends, and day of the week. The latter may be important here because people may spend more recreational time in the outdoors on the weekends. Individual-level confounders such as age and sex are naturally held constant in the case crossover design as case days are compared to control days for the same individuals.

Rainfall is understood to influence snake behavior in different ways depending on baseline climate (Goldstein et al 2021, Chaves et al 2015, Angarita-Gerlein 2017, Ediweera et al 2018, Hansson et al 2009, Phillips et al 2018). To control for the unknown effect that rainfall might convey on snakebite events in Georgia, we added zip code specific daily precipitation to our models. We also added zip code specific daily dew point to our models, noting that studies have found different relationships between snakebite events and humidity depending upon region, species, and baseline climate (Shashar et al 2018) (Ediweera et al 2018))(Ferreira et al 2019).

To investigate seasonal variation in the effect of temperature on snakebite events, we ran stratified analyses by season. Winter was defined as any event occurring from December to February. Spring was defined as March to May. Summer was defined as June to August, and fall as September to November.

Finally, to explore spatial distribution of snakebite events, we performed a simple cluster analysis. Several clustering methods were explored including Global Moran's I, Local Moran's I with various neighbor definitions, empirical bayes smoothed Local Moran's I, and the Kulldorf spatial scan. After exploring various neighbor definitions for zip codes, we decided on inverse distance weighting for Local Moran's I due to variation in the size of Georgia zip codes.

This study was approved by the Institutional Review Board of Emory University. All statistical analyses were performed in R 4.0.2. All spatial analyses were performed in QGIS version 3.18 and GeoDa 1.180.

Results

Table 2 reports the number of each event, including by year. Of the four outcomes, the 'toxic effect venom' category was the most frequently occurring (n= 48,248) over the study period; snake-specific events were relatively rare. Of the three snake-specific outcomes, we focus our reporting on the most common "any snakebite" outcome (n=3,574). Of all bites, 77.92% were coded as 'venomous' (n=2,785). The 'venomous snakebite' and the 'any snakebite' outcome increased each year over the study period, corroborating data from the Georgia Poison Control Center (Table 2) (Snakebites 2020 GA PCC).

Table 2) ICD Event totals and mean events per day for the whole study period and stratified by year.

Outcome	***2014-2018 Total Events N (Mean Per Day)***	***2014 Total Events N (Mean Per Day)***	***2015 Total Events N (Mean Per Day)***	***2016 Total Events N (Mean Per Day)***	***2017 Total Events N (Mean Per Day)***	***2018 Total Events N (Mean Per Day)***
Venomous Snakebite	2,785 (1.54)	459 (1.27)	567 (1.57)	575 (1.58)	585 (1.60)	599 (1.66)
Non-Venomous Snakebite	825 (0.46)	183 (0.51)	133 (0.37)	163 (0.45)	171 (0.47)	175 (0.49)
Any Snakebite	3,574 (1.97)	641 (1.78)	696 (1.92)	729 (2.01)	742 (2.04)	766 (2.12)
Toxic Effect Venom	48,248 (26.74)	11,608 (32.16)	10,762 (29.73)	9,321 (25.68)	10,026 (27.54)	10,285 (28.49)

Seasonally, the mean counts for all events were highest in the summer. This finding is curious as biological literature on southeastern snakes purports spring to be the most active season (Jensen et al 2008). Summer was closely followed by fall, then spring and winter respectively. The non-snake 'toxic effect venom' code showed a similar pattern.

Table 3) ICD Event Totals by season

Outcome	Fall *N (Mean/Day)*	Winter *N (Mean/Day)*	Spring *N (Mean/Day)*	Summer *N (Mean/Day)*
Venomous Snake Bite	798 (1.75)	47 (0.11)	664 (1.44)	1,276 (1.82)
Non Venomous Snake Bite	219 (0.48)	28 (0.06)	217 (0.47)	361 (0.79)
Any Snake Bite	1006 (2.21)	71 (0.16)	872 (1.90)	1,625 (3.53)
Toxic Effect Venom	12,493 (29.67)	1,859 (4.43)	6,875 (16.84)	27,201 (62.67)

Figure 1 displays the association between temperature and snakebite event counts. It shows that snakebite events appear to cluster towards higher temperature days. Mean maximum temperature for the whole state is plotted against total count of 'any snakebite' event across the state to create the following figure.

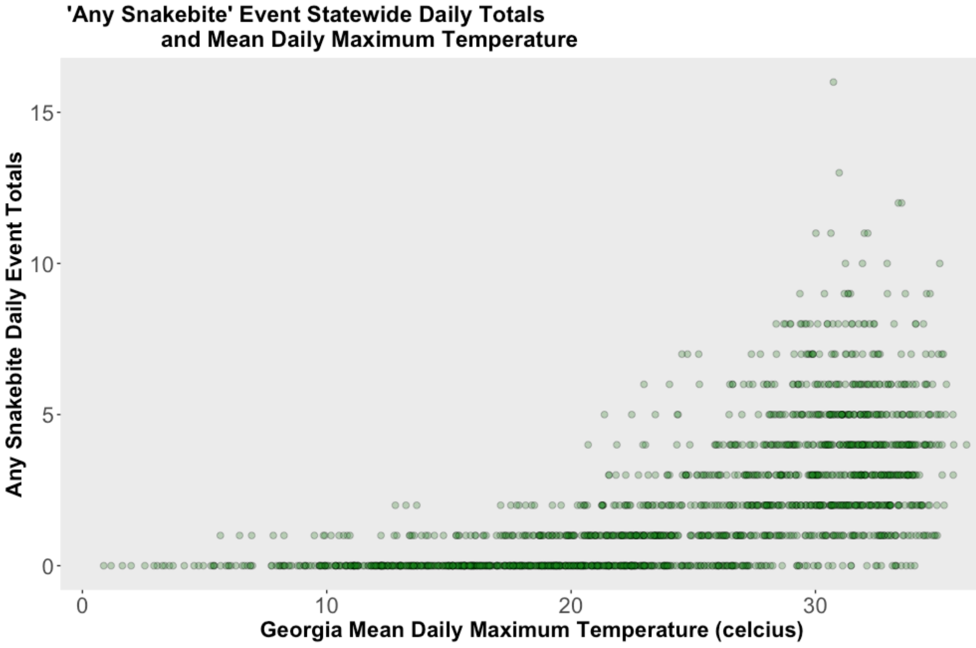

Figure 1) This figure shows the rough association between 'any snakebite' event counts and temperature. The Y axis plots the total 'any snakebite' events for a given day across the whole state. The X axis plots the mean daily maximum temperature for the whole state (mean of maximum temperature in every zip code on a specific date).

Cluster Analysis

Due to small counts and non-normally distributed data, cluster analyses were unstable to the statistical method chosen. Global Moran's I tests for whether clustering is present at all in the dataset. The (non-smoothed) Moran's I of 0.294 indicated that there is moderate spatial autocorrelation. The inverse distance weighted Local Moran's I identified a high cluster in the suburban zip codes surrounding Atlanta. The most urban central zip codes are low count areas surrounded by high count areas. Figure 2 shows the spatial distribution of event counts in Georgia. Higher event count zip codes appear to be clustered around the Atlanta-metro area.

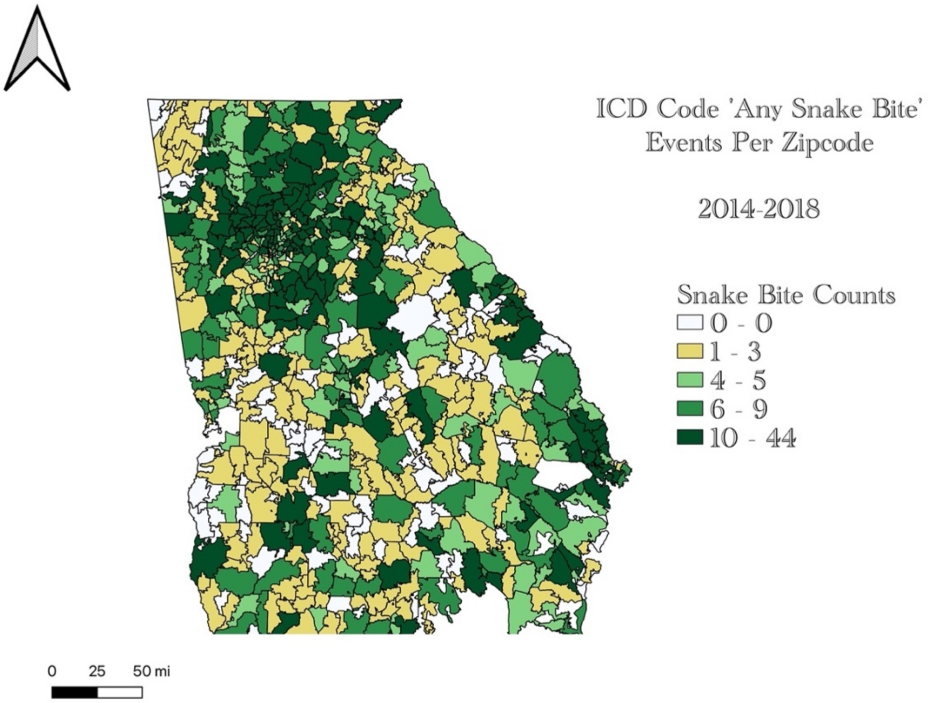

Figure 2)
This map shows spatial distribution of the 'any snake bite' ICD event code in Georgia. Counts for each zip code are totaled for the whole five year study period. Quantile categorization was used.

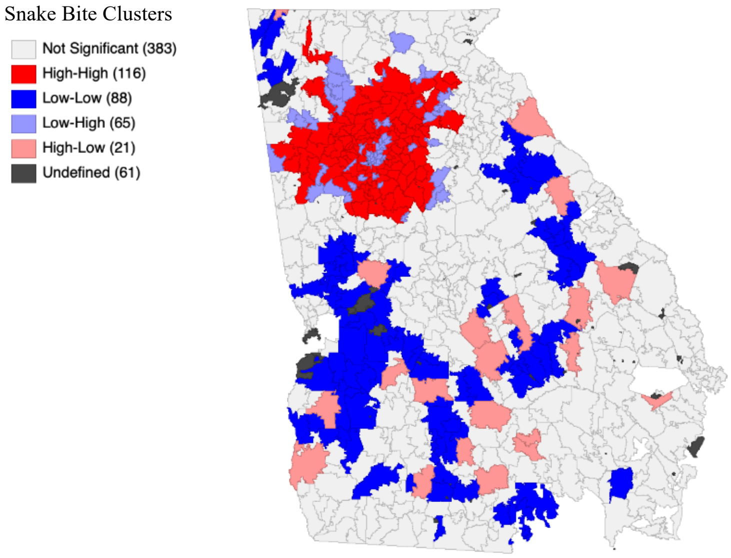

Figure 3)
Local Moran's I- Inverse Distance Weights
This map shows clusters for 'any snake bite' event using the Local Moran's I method. All colored space corresponds to a statistically significant cluster ($p<0.05$). Red area is identified as the high-high cluster (higher than average counts in both index zip codes and neighbor zip codes). Dark blue represents low-low clusters. Light blue represents zip codes that have low counts themselves but have high-count neighbors. Pink represents high count zip codes which have low count neighbors. Moran's I (0.221). Inverse Distance Bandwidth 91,000 meters

When population of each zip code is considered, cluster analysis produces contrasting results. We employed an empiric bayes smoothed Local Moran's I which uses the population rate of snakebite events as a Bayesian prior. This method identifies North Georgia as a high-high cluster and the Atlanta area as a low-low cluster.

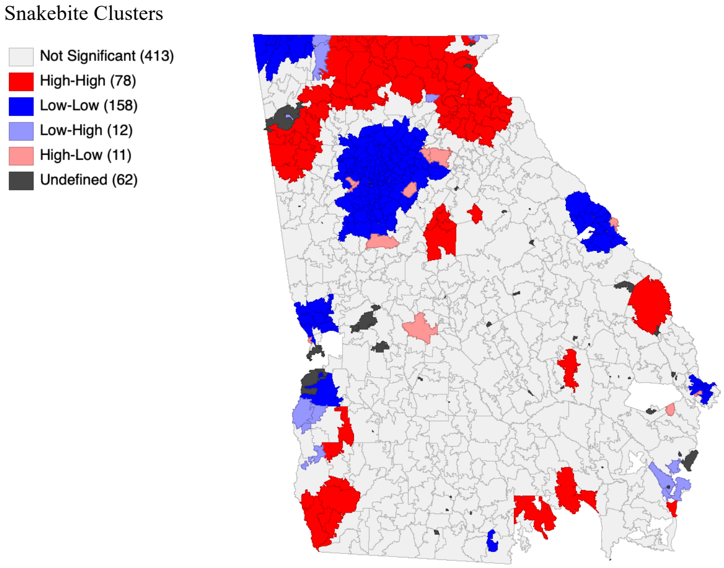

Figure 4)
Empirical Bayes Smoothed Local Moran's I
This map shows clusters for 'any snakebite count' event using the Local Moran's I method with empirical bayes smoothing. All colored space corresponds to a statistically significant cluster ($p<0.05$). Color coding is consistent with figure 6. Moran's I (0.286). Inverse Distance Bandwidth 91,000 meters

The most comprehensive spatial method we employed was the Kulldorf Poisson spatial scan. This method considers the population of each zip code in cluster analysis. Like Empirical Bayes smoothed, this method identifies a North Georgia cluster, but also a huge cluster in the southeastern plains and southern coastal plain. Kulldorf Poisson results were consistant with relative risk maps (see appendix) which also identified high risk zip codes in the Georgia plains regions.

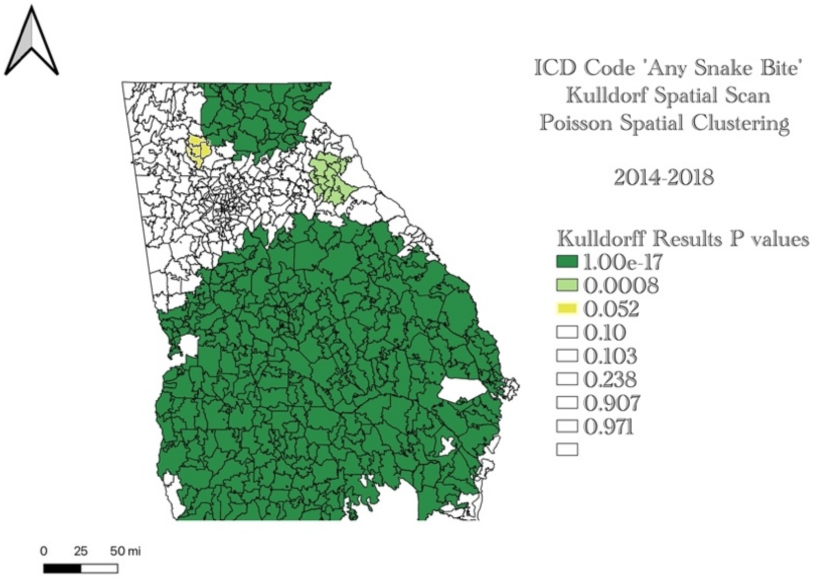

Figure 5) Kulldorf Spatial Scan
This method considers the population at risk in each zip code. Large areas are identified as 'high rate' clusters. These areas are depicted in dark green. The light green area is another statistically significant high rate cluster. The yellow area just North of Atlanta is determined a high rate cluster, although not statistically significant, but nearly so with a p value of 0.052

Due to unstable results all spatial analyses performed should be considered exploratory. Our dataset is subject to the small numbers problem with too short of a study period to amalgamate sufficiently high counts for consistent spatial analyses. Depending upon the importance placed on population at risk, either suburban metro Atlanta, North Georgia, or the plains region may be considered highest risk cluster areas for snake bites.

Associations with temperature

Conditional logistic regression models showed that all outcomes had positive associations with temperature (Table 4). This was observed in unadjusted models as well as with control for precipitation and dew point, though the controls reduced the effects somewhat. In both cases, the associations between temperature and snake-specific outcomes were notably stronger than the association found with non-snake 'toxic effect venom' events.

Table 4) Fully Adjusted Model Maximum Temperature- Whole Study Period

ICD Outcome	**OR for Max Temp Unadjusted (CI)**	**OR for Max Temp Adjusted *(CI)***
Any Snake Bite	**1.098** (1.08- 1.11)	**1.064** (1.04 - 1.08)
Venomous Snake Bite	**1.101** (1.08-1.11)	**1.061** (1.04 - 1.08)
Non-Venomous Snake Bite	**1.093** (1.06-1.12)	**1.073** (1.03 - 1.11)
Toxic Effect Venom(new)	**1.057** (1.05-1.06)	**1.042** (1.04 - 1.05)

When stratified by season, we found that the association between temperature and snake bite events was strong and significant in the spring and fall ($p < 0.05$) (Figure 6). This was true for both the 'any snakebite' and 'venomous snakebite' event. Non-venomous snakebite showed a similar pattern, but with more uncertainty. We found that the association between temperature and all snake-specific outcomes was weak and non-significant in summer. Winter estimates for all three snake specific outcomes were uncertain (wide confidence intervals) and not significant. The association for toxic effect venom was significant in all seasons. See Figure 6 for visualization of odds ratios for maximum temperature in fully-adjusted, season-stratified models. See the appendix for odds ratios for maximum temperature, dewpoint, and precipitation in these models.

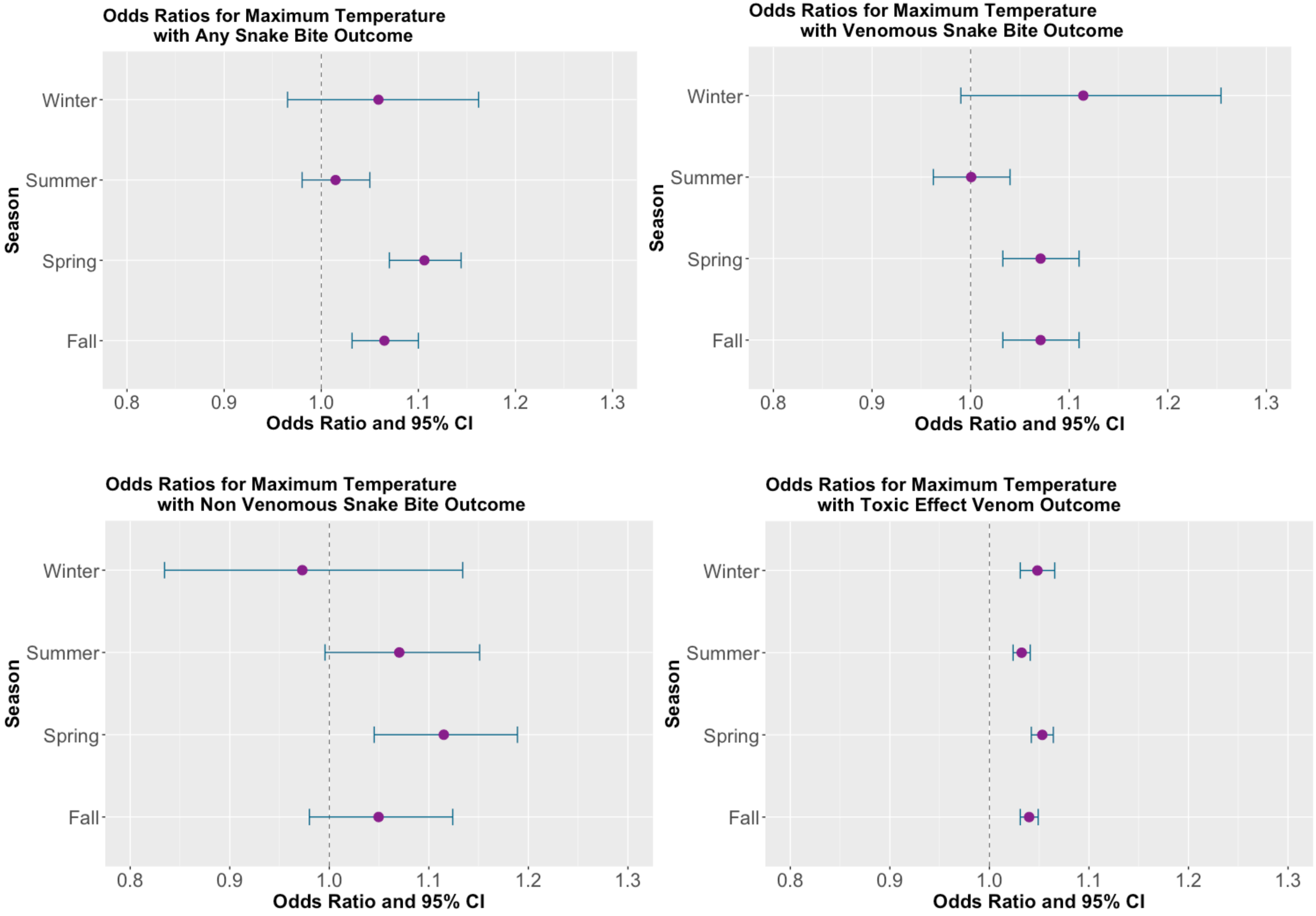

Figure 6) Each quarter plot is representative of an ICD outcome. The OR for maximum temperature is plotted for each season. The highest OR's with narrow CIs are produced in Spring and Fall. All snake-specific outcomes have wide confidence intervals for winter suggestive of under-power. Toxic Effect Venom estimates are smaller than snake-specific estimates with tight confidence intervals.

Discussion

We found that maximum temperature was significantly and positively associated with snake-specific outcomes for the whole study period in both adjusted (OR 1.098, $p<0.05$) and unadjusted models (OR 1.064, $p<0.05$). In season-specific models we found temperature to be the strongest predictor of snakebite events in spring and fall. Temperature was a weak or insignificant predictor in winter and summer. Our snake outcomes had stronger associations with temperature than the 'Toxic Effect Venom', which does not include snakes.

Snakes are ectotherms (cold-blooded) in that they lose heat through metabolic processes and are greatly impacted by ambient temperature (Jensen et al 2008). Their reptilian ectothermic identity lends snakes highly responsive to external temperature. With that said, one might expect differences in the way temperature effects snake activity due to dormancy periods that snakes engage in. Our findings are consistent with this paradigm.

Temperature is most strongly predictive of snakebite events in fall and spring when snakes are in a highly dynamic state either arising from brumation (spring) or initiating dormancy (winter). Short-term temperature fluctuations in fall and spring may impact whether snakes are active at all. Most snake species in Georgia mate in spring and are birthing their young in the fall, further increasing activity at these times (Jensen 2008).

In Georgia summers and winters, temperature was not found to be predictive of snake bites. The winter stratification may have been under-powered to detect an effect as only 71 'any snakebite' events occurred in the winter period. Additionally, low temperatures may be precluding snakebite events in winter. The lack of association between temperature and bites in summer is telling because snake outcomes are most frequent in summer. These results may serve as evidence that estivation (dormancy in high heat periods) is not a behavior that Georgia snakes employ. Instead, in summer, some Georgia snake species likely transition from diurnal activity to nocturnal activity because of warmer nighttime temperatures (Secor 2019). In general, snakes are understood to be highly adaptive in diel activity patterns with great flexibility in adjusting based on temperature (Abom 2012). Species-specific temperature thresholds for these shifts in activity patterns are not well-established. Copperheads, one of the most encountered venomous species in Georgia, are known to engage in this behavior (Megnak 2012) (Adams 2020). This ability of snakes to shift activity patterns to nighttime when they are unlikely to interact with humans may contribute to the lack of associative relationship between temperature and bite events during this season. Importantly, the lack of association detected in summer indicates that there may be non-meteorological variables associated with snake bite events that we did not explore in our analysis.

Yanez et al report that human behaviors are predictive of snake bite events. They state that in developing nations occupational activities such as farming are more strongly associated with snakebites, while in developed nations recreational activities are more strongly associated with bite events (Yanez 2015). Both recreational and occupational risks are pertinent in Georgia. Results from our exploratory cluster analyses help generate hypotheses for human behaviors that may be increasing risk for snake bites. Figures 2 and 3 point to suburban areas where individuals may engage in activities such as yard-mowing, gardening, and weed removal which may increase opportunity for human/wildlife conflict. Figures 4 and 5 highlight North Georgia where outdoor recreation may elevate snakebite risk. Figure 5 identifies the coastal and southeastern plains regions of Georgia where heightened agricultural activity may increase risk for snakebite.

Adams et al state that with continued urbanization in the southeastern United States, human-wildlife conflict with the Copperhead, can be expected to increase in the future (Adams 2020). Adams et al performed a detailed analysis on snake striking behavior and find that upon a human encounter, copperheads are more likely to remain concealed or flee as opposed to engaging in self-defense (Adams 2020). This finding is supportive that it may be the human activity more so than the snakes' that precipitates bite encounters in southeastern summers. Future studies on predictive factors of snake bites may consider interviewing patients for activities preceding bite events.

As a public health topic, the literature base on predictive factors for snake bite events is scant both internationally and domestically. In Israel, Shasar et al found that higher temperatures and lower humidities were associated with an increase in snake bites (Shasar 2018). In Sri Lanka, Ediweera et al also found that decreased relative humidity and increased temperature were positively associated with snake bites. Our findings were consistent with these two studies in temperature but not humidity. Another study in Sri Lanka used an agent-based model to incorporate both climatic and human factors. This study used precipitation as the only climatic predictor but several farmer activity predictors such as number of hours worked, starting hour, percentage of population working as farmers, and farmer type. That study complements ours in suggesting that human behaviors may be predictive of snakebites. In Costa Rica, Chavez et al find that snakebites are more likely to occur at higher temperatures and in areas with heavy rainfall (Chaves 2015). These results are consistent with ours in temperature only, not rainfall. Again, in Costa Rica, Hannson et al consider low elevation and high humidity as spatially predictive of high risk snakebite areas for the most dangerous species in that region, Bothrops asper (Hannson 2013). These results are consistent with ours in humidity. In California, Phillips et al found that snake bite incidence increases with precipitation if preceded by drought (Phillips et al 2018). These results are inconsistent with ours as we did not find precipitation to be a significant predictor of snakebite events although we did not account for drought periods. In our literature review, we found no recent publications modeling predictive factors of snakebites in the southeastern United States. Our findings add a meaningful contribution to that end.

There are several limitations to our study. One important limitation to emphasize is that the reported zip code of the patient may or may not be reflective of where the snake bite occurred. This could create exposure misclassification in which bite events are not paired with the nearest maximum temperature for modeling. For example, individuals who live in Atlanta frequently travel to North Georgia to go hiking and camping. Such individuals who experience snakebite events will report their home zip code when they receive treatment. The home zip code may be distant to the location of the snake encounter. Furthermore, not all snakebite events are captured by emergency department visits. Many individuals may have a snakebite encounter and not seek medical attention in an Emergency Department.

Another limitation of our study was low counts and a short study period. A longer study period could help ameliorate the small numbers problem in seasonal stratification and in spatial analysis. Another possible outcome of interest might be veterinary snake bite event data. Dogs in

Georgia are known to be particularly vulnerable to snake bites. The relationship that pet snake bites have with meteorological predictors of interest may provide useful for comparison to human outcomes.

Zip code specific climate data was the smallest unit of analysis we could access for this study. However, it is important to note that snakes are responsive to temperature variation on the micro-climate scale. There can be great differences in the temperature experienced by a snake in a shady as opposed to a sunny spot, or a creek bank as opposed to pavement. We were unable to take micro-climate variation into account in our study. This level of measurement may not be feasible for future studies due to obvious challenges in determining temperature at the exact moment in space and time of the snakebite event.

Lastly, with our outcome data being derived from ICD codes, we have no way of parsing out species-specific snake behavior in relation to meteorological variables. For instance, if most events recorded involved Copperheads, our findings are most applicable to Copperheads and not necessarily to all snake species.

Our results may have implications as to how to expect a changing Georgia climate may impact human/wildlife conflict with snakes. In general, climate change is expected to impact geographic distribution of snakes in North America (Yanez-Arenas 2016). Additionally, our findings suggest that warmer and/or longer fall or spring seasons could impact the morbidity of snakebite events in those transition seasons. With longer fall or spring, more snake bites may be expected. Warmer spring or fall may increase the likelihood of experiencing snakebite to a point.

Upon reaching summertime temperatures we would not expect climate change to impact biting because in this season temperature was not predictive of snake bites. The timing of season change could also impact when we might expect higher risk for snakebite events. For instance, earlier spring or later fall may cause high risk times for snakebite to shift to earlier or later in the year.

Conclusion

Temperature was found to be positively associated with snake bite events. Whole study period models produced positive and statistically significant associations for temperature for all three snake-related outcomes (reference table 4). In our fully adjusted models, dewpoint was also a significant predictor of snakebites, but not as strong as temperature. For the 'any snake bite' outcome a one degree increase in temperature raised the odds of experiencing a snake bite 6.4% and a one degree increase in dew point raised the odds of experiencing a snake bite by 4.9%, holding precipitation constant. Precipitation was not a significant predictor of experiencing snake bites in Georgia.

Seasonal stratification further clarifies the relationship that weather has with snake activity. In fall and spring, temperature and dew point are positively and significantly associated with 'any snake' and 'venomous snake' ICD outcomes. In summer, the season with the highest snake bite event counts, temperature nor dew point were significant predictors of snakebites. We are confident that our study provides valuable contributions to understanding the impact that meteorologic conditions have on snakebite events, and appropriate future direction for research. Further investigation is needed to determine predictors of snake bite events in Georgia summers.

Appendix

Figure 1 addendum

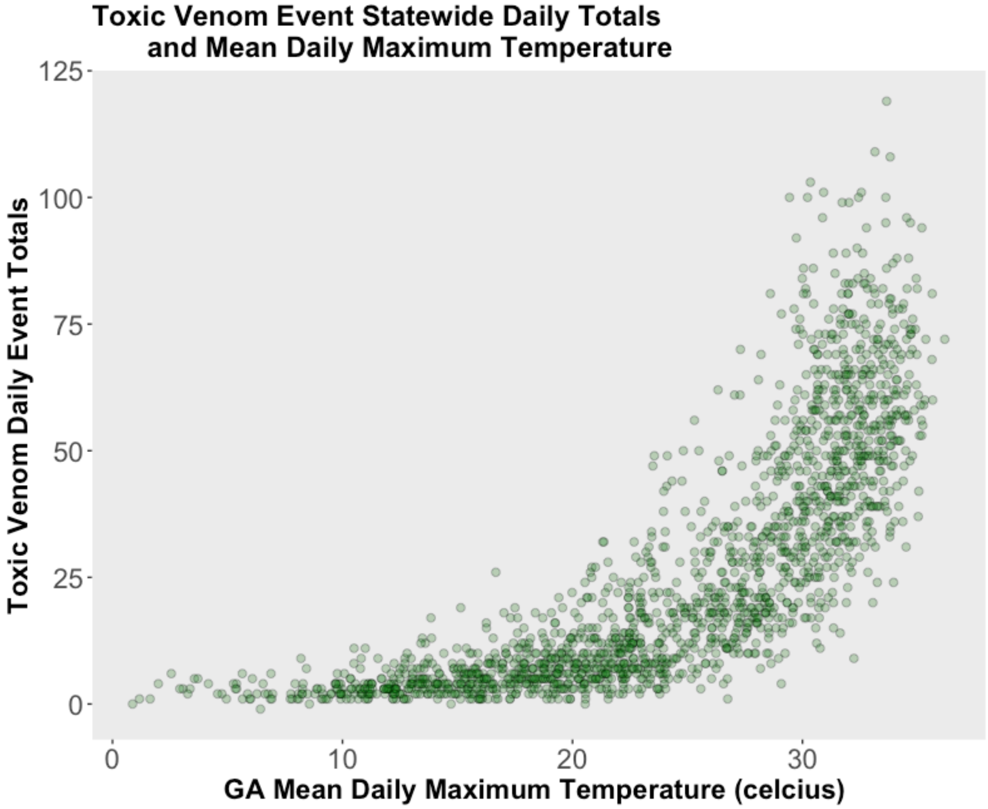

Figure 1) This figure complements Figure 1 in the text body. Like figure 1 it plots event totals for a given day across the whole state again mean daily maximum temperature for the whole state. This figure plots the 'Toxic Effect Venom Code'. Both plots show that there are higher event counts on warmer days.

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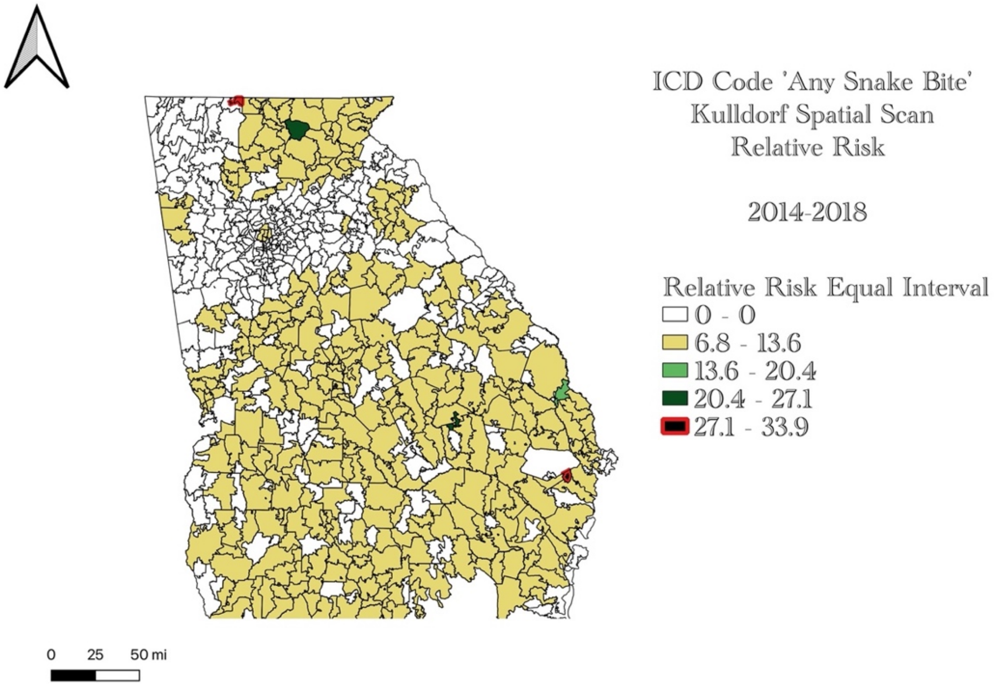
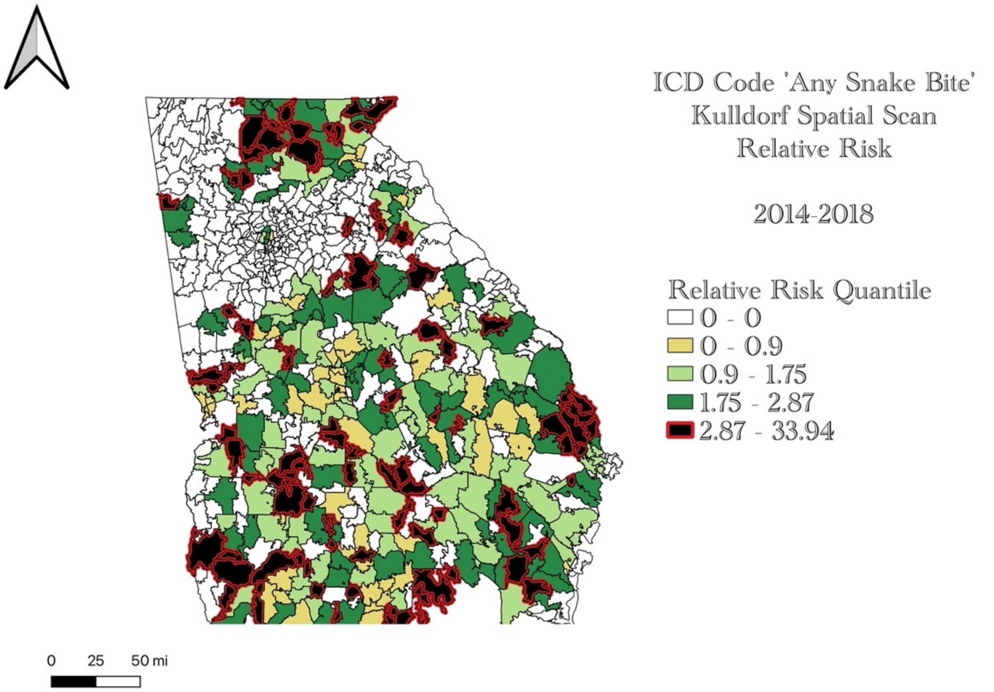
Table 5) Fully adjusted model results for the whole study period. OR's for confounders dew point and precipitation shown as well. These OR's were excluded from table 4 for simplicity

ICD Outcome	***OR Max Temp (CI)***	***OR Dew Point (CI)***	***OR Precipitation (CI)***
Any Snake Bite	**1.064** (1.04 - 1.08)	**1.049** (1.03 - 1.07)	**0.999** (0.99 - 1.00)
Venomous Snake Bite	**1.061** (1.04 - 1.08)	**1.062** (1.04 - 1.08)	**0.999** (0.99 - 1.00)
No- Venomous Snake Bite	**1.073** (1.03 - 1.11)	**1.021** (0.99 - 1.05)	**0.993** (0.98 - 1.00)
Toxic Effect Venom(new)	**1.042** (1.04 - 1.05)	**1.021** (1.02 - 1.03)	**0.997** (0.996 - 0.999)

Figure 5 addendum

The below maps are complementary to the figure 5 Kulldorf spatial scan. These maps display relative risk for snake bite in each zip code using two different categorizations. Equal interval is used in the top map and quantile categorization in the second map. Maps show that relative risk for snake bite is relatively higher in North Georgia and in the plains regions of Georgia





Season Specific Model Results-

These results are plotted in figure 6 on page 15. Here they are presented in table format.

Fully Adjusted Model Max Temp FALL	OR For Max Temp CI	OR For Dew Point CI	OR For Precipitation CI
Any Snake Bite	**1.065** 1.032 - 1.100	**1.048** 1.019 - 1.077	**1.004** 0.997 - 1.011
Venomous Snake Bite	**1.071** 1.033 - 1.110	**1.054** 1.021 - 1.088	**1.005** 0.997 - 1.013
Non Venomous Snake Bite	**1.049** 0.980 - 1.124	**1.037** 0.981 - 1.096	**0.997** 0.980 - 1.014
Toxic Effect Venom(new)	**1.039** 1.031 - 1.049	**1.025** 1.018 - 1.032	**0.999** 0.997 - 1.001

Fully Adjusted Model Max Temp WINTER	OR For Max Temp CI	OR For Dew Point CI	OR For Precipitation CI
Any Snake Bite	**1.059** 0.965 - 1.162	**1.014** 0.934 - 1.101	**0.961** 0.919 - 1.003
Venomous Snake Bite	**1.114** 0.990 - 1.254	**1.005** 0.905 - 1.116	**0.981** 0.937 - 1.027
Non Venomous Snake Bite	**0.973** 0.835 - 1.134	**1.033** 0.906 - 1.179	**0.929** 0.846 - 1.020
Toxic Effect Venom(new)	**1.048** 1.031 - 1.066	**1.007** 0.992 - 1.022	**0.995** 0.989 - 0.999

Fully Adjusted Model Max Temp SPRING	OR For Max Temp CI	OR For Dew Point CI	OR For Precipitation CI
Any Snake Bite	**1.106** 1.070 - 1.144	**1.055** 1.027 - 1.085	**0.996** 0.985 - 1.007
Venomous Snake Bite	**1.071** 1.033 - 1.110	**1.054** 1.021 - 1.088	**1.005** 0.997 - 1.013
Non Venomous Snake Bite	**1.115** 1.045 - 1.189	**1.030** 0.978 - 1.085	**0.986** 0.960 - 1.013
Toxic Effect Venom(new)	**1.053** 1.042 - 1.064	**1.032** 1.023 - 1.041	**0.996** 0.992 - 0.999

Fully Adjusted Model Max Temp SUMMER	OR For Max Temp CI	OR For Dew Point CI	OR For Precipitation CI
Any Snake Bite	**1.015** 0.980 - 1.050	**1.031** 0.993 - 1.072	**0.997** 0.983 - 1.005
Venomous Snake Bite	**1.001** 0.962 - 1.040	**1.046** 1.001 - 1.092	**0.995** 0.986 - 1.005
Non Venomous Snake Bite	**1.070** 0.996 - 1.151	**0.994** 0.918 - 1.076	**0.999** 0.981 - 1.019
Toxic Effect Venom(new)	**1.032** 1.024 - 1.041	**1.001** 0.992 - 1.001	**0.997** 0.995 - 0.999

Sensitivity Model Explorations

These tables depict results for the sensitivity analysis described on page 6 of the text. Significant p values are starred *. OR is an abbreviation for Odds ratio. DP is an abbreviation for dew point. PRCP is an abbreviation for precipitation. ORs are listed in the order they are described in the column headings.

Whole Study Period Maximum Temperature

	OR For Max Temp	OR For Model with Max Temp and DP	OR for Model with Max Temp and PRCP	OR for Model with Max Temp, DP, PRCP	OR for Model with Lag 1	OR Avg of MaxTemp and Lag_1
Any Snake Bite	1.1*	1.07*, 1.04*	1.10*, 1.00	1.06*, 1.05*, 0.99	1.06*	1.09*
Venomous Snake Bite	1.10*	1.06*, 1.06*	1.11* , 1.01*	1.06*, 1.06* , 0.9	1.06*	1.09*
Non Venomous Snake Bite	1.09*	1.08*, 1.01	1.09*, 0.99	1.07*, 1.02, 0.99	1.07*	1.09*
Toxic Effect Venom	1.06*	1.05* , 1.02	1.06*, 0.99	1.04*, 1.02*, 0.99*	1.05*	1.06*

Whole Study Period Minimum Temperature

	OR For Min Temp	OR for Min Temp and DP	OR for Min Temp and PRCP	OR for Model with Min Temp, DP, PRCP	OR for Model with Lag 1	OR with Avg of MinTemp and Lag_1
Any Snake Bite	1.08*	1.09, 0.99	1.09*, 0.99*	1.08, 1.0, 0.99*	1.07*	1.08*
Venomous Snake Bite	1.1*	1.07 , 1.03	1.1*, 0.99*	1.06, 1.03, 0.99*	1.08*	1.1*
Non Venomous Snake Bite	1.06*	1.16, 0.91	1.07*, 0.98*	1.15, 0.92, 0.99*	1.05*	1.06*
Toxic Effect Venom	1.05*	1.08*, 0.96*	1.05*, 0.99*	1.07*, 0.97 , 0.99*	1.04*	1.05*

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