DISCUSSION GENERIC MODEL

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1. Revisit the previous sections to summarize or conclude.
2. Explain the results and identify the implications and achievements of the study.
3. Locate the study in the research map and explore the link with other study.
4. Point out the limitations and suggestions for further research.
(5). Identify the potential applications of the study.

months) and snakebite incidence (maximum rho = –0.52, $p \ll .01$ at 18 months prior) and drought and incidence (maximum rho = −0.17, $p = .01$ at 6 months prior). Temperature, including temperature ratio to long-term average, did not appear well correlated with incidence on its own. Precipitation and drought appeared well correlated with each other (for every 9.5% decrease in 18 month prior precipitation there was a 10% increase in 6-month prior drought); and a fitted model for snakebite incidence as a function of this performed well ($r^2 = 0.52$, residual standard error = 13%) (Supplementary Appendix Table 1). Taking each predictive variable in isolation (due to their mutual dependence) and adjusting for seasonal fluctuations, excess snakebite incidence could be calculated directly from the six month prior drought at a rate of –3.8% per +10% increase in drought, and +3.9% for each 10% increase in 18 month prior precipitation across the state of California (Figure 8) and counties.

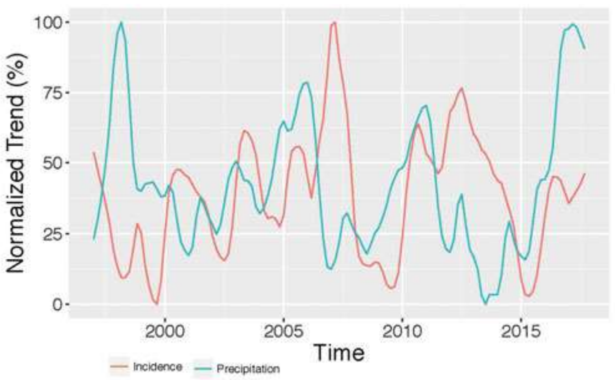

Figure 7. Normalized, seasonality adjusted precipitation compared with snakebite incidence.

Discussion

Our 20-year analysis of snakebites in California showed a well-correlated inverse relationship between snakebite incidence and severe drought phases, with a predictable increase of snakebites following precipitation. This is in contrast to popular press reports of increased snakebites with drought conditions [29,30], and Central American research that reported increased incidence of snakebite during high temperatures of El Niño Southern Oscillation (ELSO) [9]. This study also analyzed the effect of altitude and precipitation on the periodicity of regional snakebites, and found that while climate changes had a predictable effect on incidence, snakebites clustered in regions with the highest precipitation [9]. These low altitude humid regions with the hottest temperatures also saw heavier precipitation [9], which is opposite the arid drought conditions of California. As such, we cannot extrapolate the Costa Rican impact of ELSO and temperature to observed Californian trends. It has been theorized that a snake's foraging activity and subsequent human interaction may increase during hot temperatures [31,32], as a combination of decreased rodent population, riskier foraging behavior, and increased activity levels may be seen [31,33]. This has been supported by increased snakebites of sheep during drought [34]. However, these prey assumptions may be incorrect, as studies in the United States have found greater rodent populations [31,35], and by proxy, rodent vector diseases that increased during heavy precipitation phases and decreased during drought [36]. Likewise, high snakebite incidence patterns in areas with heavy precipitation have been found to have the greatest rodent populations [9]. As snakes are predominantly ambush predators of rodents and small animals [37]; the large increases of snakebite following the wettest winters in California likely reflect increased snake productivity following herbivore prey population growth.

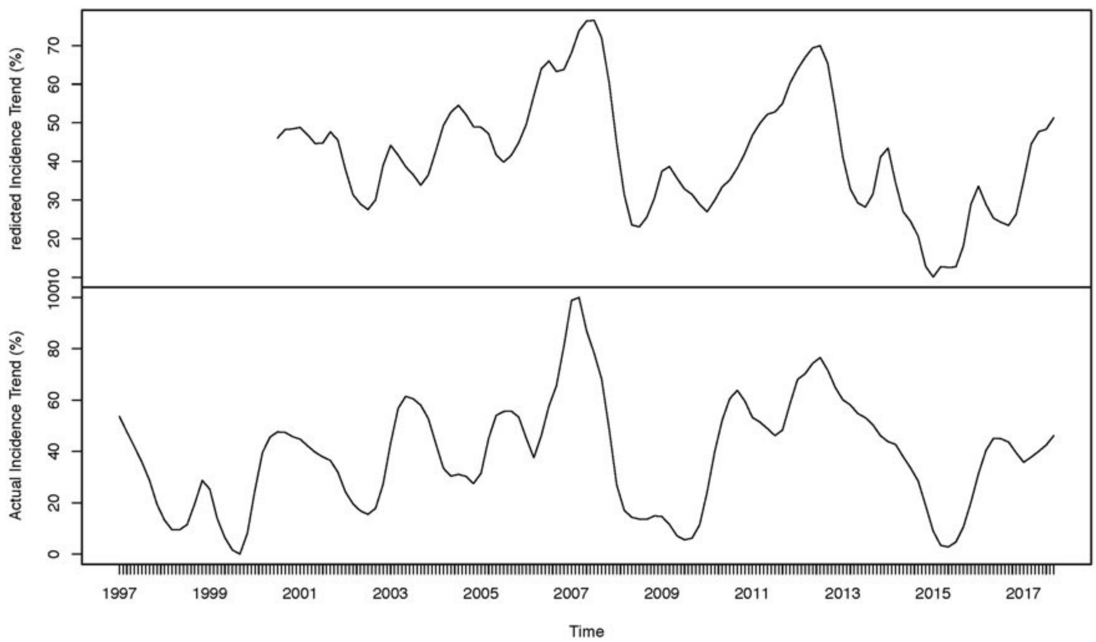

Figure 8. Predicted snakebite incidence trend using seasonality adjusted, normalized 18-month prior precipitation and 6-month prior drought indicator as predictor variables.

The patient demographics of our study were consistent with known epidemiologic trends of snakebites. The predominance of male victims were similar to the 69–79% found in state and national registries [3,18,38]. The average age of our patients was slightly higher than other registry studies [18,38], but similar to those treated in emergency departments [3], with similar fatality rates [39,40]. Approximately, 10–15% more CPCS consults were for moderate envenomations than the national average [40]. This may be due to reporting bias: as the relatively high prevalence of snakebites in California [39], regional health care providers may be comfortable without CPCS assistance and under-report snakebites with minor or no clinical effects.

Fifty-nine percent of our patients with recorded interventions received Crotalidae Polyvalent Immune Fab antivenom (FabAV; CroFab®) compared to 84% from 2013 to 2015 [38]. FabAV was approved by the US Food and Drug Administration in 2000, and has since become the mainstay of treatment with an 8% incidence of immediate hypersensitivity [41], and a 14% use increase seen in the 7 years following approval [40]. As 38% of our patients were treated with whole IgG Wyeth antivenin (which is no longer produced in the United States) [42], it is likely that the relatively low use of FabAV seen is due to a 20-year average, rather than current practice.

There was a visible comparative trend statewide with extreme weather fluctuations: the population adjusted incidence of snakebites fell in 2002–2005 and 2007–2010 during periods of drought. In 2015–2016, snakebites declined to their nadir with the most severe drought on record. After accounting for seasonal trends, we observed that prior precipitation was a strong predictor of snakebites, with incidence peaks following the heavy precipitation years of 2006 and 2011.

Limitations

Snake identification was not performed by professional herpetologists, and there was no independent verification of CPCS data, so the “rattlesnakes” reported may reflect a tendency to attribute all snakebites in an area to the predominant type [39]. The clinical outcome was unknown in 11% of the cases, and deemed unrelated to the bite in 1.7%. While lower than the 30% lost to follow-up of other AAPCC snakebite studies [39], our losses may still have affected the conclusions. The database did not provide the zip code of the injured patient, so we opted to rely on the zip code of the originating initial call to CPCS, rather than the consulted PCC which lacked locational accuracy. The initial calls were most frequently placed from a hospital setting, which means that the zip codes obtained were likely to be reflective of the general region where the bite occurred, but may not be geographically precise. This dataset cannot account for those snakebites that did not consult CPCS, and while consistent with the CPCS analysis model, it is likely an underestimate of total incidence.

We controlled for population changes per county, but could not account for changes in potential at-risk activities (e.g., an increase or decrease in outdoor recreation over time or activity changes during drought conditions). We cannot exclude the possibility that changes in the medical culture or technology of snakebite reporting may be a confounding variable. While we believe these limitations have not impacted the primary outcome of the study, future work could seek to include additional controls.

Integration and alignment of co-variate data presented unique challenges. NASA-provided re-analysis weather data are available on a uniform grid that is not aligned with geographic features, where aggregation results in more data for larger counties and less data for smaller. Particularly, San Francisco county was excluded from our analysis due to lack of available data. Climatological variable analysis was not possible at county resolution. While US Census data (population and demographics) did not present similar challenges, current-year census statistics were unavailable so 2016 data were used as a proxy for 2017. Unavailability of drought data prior to 2000 limited our analysis of that variable to the coincident years of 2000–2017 and prevented direct comparison with precipitation, air temperature, and incidence during the years 1997–1999. Future studies may consider analysis at smaller spatial resolutions if higher resolution long-term climatological data are made available.

Conclusions

Climate and extreme weather patterns appear to have had a significant and predictive effect on human–snake interactions in California over a 20-year period. The novel finding that snakebite incidence decreased following drought, and increased following precipitation has not been previously reported. This study confirms prior results for the demographic and geographic distribution of snakebites, and presents new results describing the interaction with climatological variables that emerged only when adequately adjusting for population growth and seasonality. Awareness of these trends may assist the public with seasonal snakebite risk assessment, medical provider preparations for antivenom requirement, and appropriate resource allocation to further study the impact of climate change on venomous species and human health.

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Disclosure statement

The authors declare no conflicts of interest, funding, or financial benefit arising from this study.

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