The eco-epidemiology of snakebite and the benefits of redefining as a zoonosis

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Background

Snakebite is still one of the deadliest and neglected of the class-A neglected tropical diseases, which also makes it one of the least understood. Despite being non-infectious, venom transmission is remarkably similar to rabies' zoonotic transmission from dogs to humans, although snakebite is simpler because venom prevalence, unlike rabies, is 100% among its hosts (medically-relevant snakes). The main obstacle to better understand snakebite is the cryptic nature of most venomous snakes. To show the benefits of redefining snakebite as a zoonosis we estimated the geographic patterns of snakebite envenoming incidence using mathematical models for directly transmitted zoonotic infectious diseases.

Methods

We analysed published geostatitical estimates of snakebite incidence in Sri Lanka from a community survey, using estimates of the geographical abundance of seven venomous snakes alongside land cover maps as surrogates of occupational and socioeconomic risk factors and human population density. To estimate patterns of venomous snake abundance we used occurrence records of the seven snake taxa that occur in Sri Lanka *(Bungarus caeruleus, B. ceylonicus, Daboia russelli, Echis carinatus, Hypnale spp., Naja naja and Trimeresurus trigonocephalus).* Snake occurrence data were analysed with point process models in relation to the climatic conditions considered optimal for each species and land cover-derived variables. We combined the snake abundance estimates with human population density and land cover using a series of mathematical models representing human-snake contacts.

Results and discussion

Snakebite is best represented by a two-part process, 1) the bite and 2) envenoming. Bites are a function of the product of human and snake abundance, the impact of humans on snake abundance in each type of land cover, and individual snake species contact rates that summarise certain key factors. Given that snakes are more abundant in areas less impacted by humans, per capita risk of bites is higher in forest, followed by agricultural, degraded forest, urban and tea has the lowest. The probability that bites result in envenoming depends on the biting species and land cover again (indicating important occupational risk factors). Even though per capita risk was higher where populations are smaller, urban areas may have the largest number of envenoming bites in light of population size (Figure 1). Mathematically, bites follow the classic mass-action product of infectious (snakes) and susceptibles (humans) population density. The variability of contact rates between land cover likely arises because it acts as a surrogate of occupational risks. In all of the tested models, snake abundance decreased with increasing human population density, which indicates that there is ecological competition resulting in higher incidence rates in sparsely populated areas (forests).

The snake factors that were measured and influence estimated rates are aggressiveness (affecting bites), and venom toxicity (affecting envenoming). Other factors that may influence rates but were not measured are overlap of activity with farmers and frequency of venom injection after a bite, which is known to vary between snake species.

With our analyses we show some of the mechanistic underpinnings of snakebite incidence estimates: 1) climate regulates both geographic patterns of snakebite incidence and agricultural practices; 2) humans compete ecologically with snakes for space displacing them; 3) land cover represents a surrogate of human occupational risk factors. These factors make of snakebite a socioecological system whose epidemiology is susceptible to shift spatially with global change (climate, land use, socioeconomic and demographic).

Climate will affect many snake-related and food production processes, occupational risk factors and some of the effects of land use on snakebite epidemiology. Land use change could further create environmental conditions that affect or benefit the different snake species, and socioeconomic change will modify existing occupational risk factors, but also to the availability of treatment and prevention strategies. Finally, demographic change will likely keep driving land use change and competition and displacement of snakes.

Our analyses based on zoonotic spillover ecology show that there is great potential for better understanding snakebite as a dynamic system. Furthermore, we show that long-term snakebite mitigation should account for the ongoing process of global change.

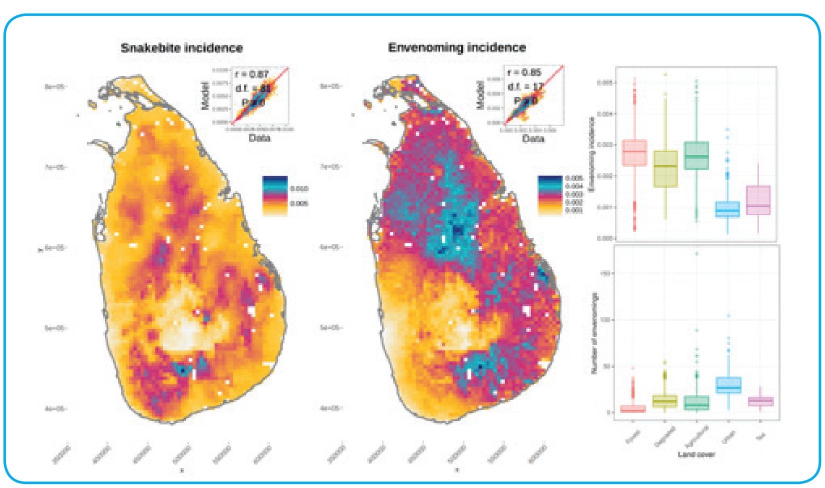

Figure 9: Snakebite (left) and envenoming (centre) incidence estimates by our model. Insets in the top right corner of each map show a comparison with the estimates used to fit and select models. Blue indicates high incidence, and white indicates lower. Rightmost panels are a summary of the envenoming incidence rates (top) and total number of envenomings (bottom) per spatial unit in each of the considered land cover types (x-axis).