Periodic model predicts the spread of Lyme disease

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Blacklegged ticks are known as one of the disease transmitting organisms for Lyme disease. Credit: CDC

Lyme disease is among the most common vector-borne illnesses in North America, Europe, and some parts of Asia. A spirochete bacterium called *Borrelia burgdorferi* causes the disease, and blacklegged ticks (*Ixodes scapularis*) are responsible for the majority of North American transmissions. Commonly known as deer ticks, blacklegged ticks exhibit two-year life cycles with the following four stages: eggs, larvae, nymphs, and adults. Larvae primarily attack white-footed mice, then become nymphs upon obtaining a blood meal. At the beginning of their second year, nymphs transform into adults and prey almost solely on white-tailed deer. Female ticks produce approximately 2,000 fertile eggs throughout their lives, nearly all of which hatch and continue the sequence.

In the past, researchers have used various modeling techniques—including reaction-diffusion models, simulation models, and temperature-driven maps—in attempts to better understand Lyme disease. In a paper publishing on Thursday, April 20 in the *SIAM Journal on Applied Dynamical Systems*, Xiunan Wang and Xiao-Qiang Zhao present a periodic time-delayed model of Lyme disease that incorporates seasonality and climate factors. "Seasonal variations in temperature, humidity, and resource availability have a strong effect on tick population dynamics," Wang said. "Climate impacts tick survival mostly during nonparasitic periods of the life cycle. Outside certain ranges of temperature and rainfall, tick populations cannot survive because these conditions directly kill the ticks or inhibit host-seeking activity."

Previous models of the disease inspired the authors' current model, which handles seasonality and tick feeding activity particularly well. "We incorporate seasonality by assuming that the birth rate of ticks, the biting rate of ticks, and the strength of density dependence for adult ticks are positive, continuous, and periodic functions," Wang said. The authors address the larvae, nymph, and adult stages of the deer tick, and incorporate mice and deer as host populations. They identify three parameters to represent the different feeding durations of larvae, nymphs, and adults.

"We need to be clear with the life cycle of ticks, including when they feed on two different hosts and how long they stay on the hosts," Wang said. "Involvement of three different tick life stages and two different hosts results in an eight-dimensional non-autonomous model with three different time delays." Wang and Zhao also identify variables for the densities of susceptible and infected mice, the densities of both uninfected and infected ticks at all stages of life, the density and birth rate of deer, mortality rates and feeding durations of all involved parties, susceptibility to infection, and individual biting rates of ticks.

The authors evaluate all parameters and apply their model to Lyme disease transmission in Long Point, a hamlet in Ontario, Canada where the disease is widespread. "In recent years, northward invasive spread of the endemic tick vectors from the United States to nonendemic Canadian habitats has become a public health concern," Wang said. "Migratory songbirds play an integral role in the wide dispersal of ticks. Long Point Provincial Park on the northwestern shore of Lake Erie is famous for its migrating birds during spring and fall, and attracts thousands of birdwatchers. It is also one of the places where infected ticks are commonly found."

Wang and Zhao utilize an existing algorithm to derive the basic reproduction ratio (R0), which acts as a threshold parameter when defining the model's global dynamics. They then use published data about monthly mean temperatures in Long Point from 1981-2010 to experiment with R0 levels, given changes in tick larvae birth rate. If R01, it will likely persist and exhibit periodic fluctuation.

Ultimately, the authors' model yields a disease-free periodic solution. If nothing is done in the next few years, Lyme disease will be continue its prevalence in Long Point and exhibit periodic fluctuation. However, reducing the recruitment rate of tick larvae could eliminate it. The authors offer a few suggestions on how best to reduce this rate and prevent tick eggs from hatching into larvae. "It may be helpful to regularly search for the spots where adult ticks usually lay eggs, like in sheds, in woodpiles, under rocks, and in the crevices of walls," Wang said. "Since tick eggs are static, it is more feasible to focus on the clearance of eggs than to think about killing ticks of the other three life stages." However, because tick eggs are not macroscopically visible, Wang and Zhao suggest that the invention of equipment to detect them would certainly be useful.

As long as the corresponding data is available, Wang and Zhao say that researchers can apply their model to the study of Lyme disease transmission in other parts of the world. They also hope to more thoroughly investigate ticks on songbirds, given the northward spread of the parasite to areas of Canada during migration season. "Since the ticks removed from songbirds consist of susceptible and infected nymphs, we may add a periodic function term into the susceptible and infectious nymph equations of our model, respectively," Wang said. "Such periodic terms can reflect the effect of seasonal migration of songbirds."

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