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Sources and scales of heterogeneous mosquito-borne pathogen transmission

Mosquito-borne diseases pose tremendous public health challenges in a variety of ecological and epidemiological contexts throughout the world. Efforts to control mosquitoes and the pathogens that cause these diseases have relied heavily on insights from mathematical modeling. In particular, the seminal work by Ross and Macdonald completed around 1970 has had a tremendous and lasting influence on research and policy since then. Nonetheless, predictions based on the Ross-Macdonald model often clash with real-world observations, largely because the model ignores empirically well-supported heterogeneities in transmission. To reconcile these deficiencies in existing theory, we develop a new model focused on the ecological and epidemiological context of encounters between mosquitoes and vertebrate hosts. This model features discrete, spatially referenced sets of locations for larval mosquito development and separate locations for mosquito blood feeding on hosts. It accounts for mosquito movement behavior, host movement patterns, and host attractiveness to blood-seeking mosquitoes.

Analysis of the model produces new metrics of mosquito-borne pathogen transmission that show how host movement patterns, variation in host biting attractiveness, and landscape geometry combine to introduce heterogeneities into the transmission process. Although the consequences of heterogeneous transmission for disease dynamics have been investigated previously, mechanistic explanations of what underlies these heterogeneities have been lacking. Another poorly understood issue in spatial models throughout population ecology is the spatial scale at which encounters between individuals are well mixed. Using an evenness index applied to location- and individual-specific metrics of transmission, we show how mixing can be measured across scales.