Modelling the Effects of Demographic and Environmental Noise on Mosquito-Borne Disease Outbreaks

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Background

- Mosquito-borne diseases are a significant public health burden.
- Environmental factors, like temperature and humidity, indirectly affect mosquito-borne disease transmission through their impact on mosquito and pathogen life history traits (Mordecai et al., 2019).
- Climate change is altering and increasing the variability of weather patterns, and will likely have an impact on mosquito-borne disease dynamics and the efficacy of control efforts.

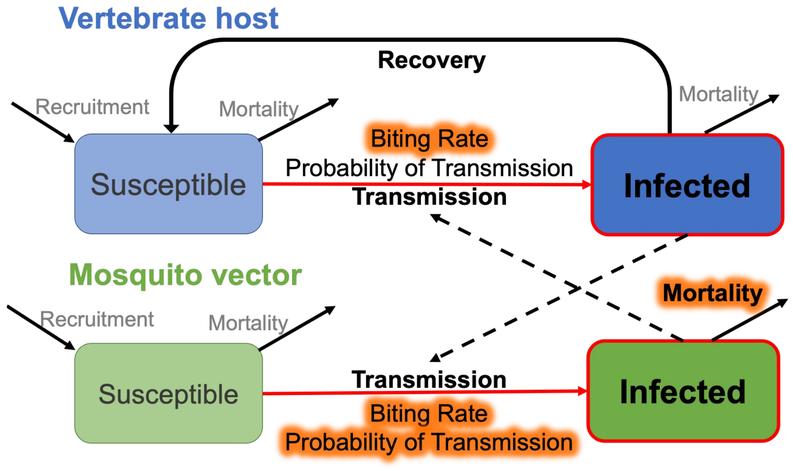
Objectives

We adapted the Ross-Macdonald mosquito-borne disease model (Smith et al., 2012) to include environmental and demographic noise to explore the dynamics of mosquito-borne diseases in response to stochasticity:

1. How do demographic and environmental noise affect the probability and intensity of mosquito-borne disease outbreaks?
2. How does the strength of environmental noise affect the probability and intensity of mosquito-borne disease outbreaks?

Methods

In the model, mosquito and host populations are constant (with overall equal recruitment and mortality rates); only infected population is tracked.



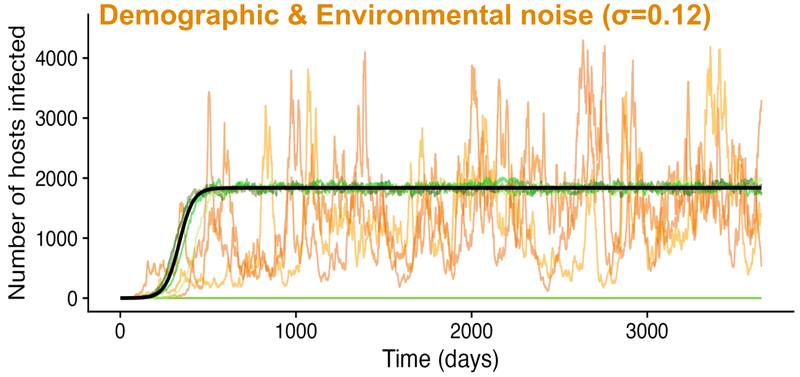
Demographic noise-Makes events (e.g. transmission, recovery, mortality) occur randomly on the infinitesimal time scale

Environmental noise (strength σ) -controls the variability of biting rate, mosquito mortality rate, and probability of transmission from host to mosquito

- Ran 1000 batches of 100 simulations to get a sampling distribution for probabilities of endemic disease and outbreaks
- Tested 7 R_0 values and 21 environmental noise strength values

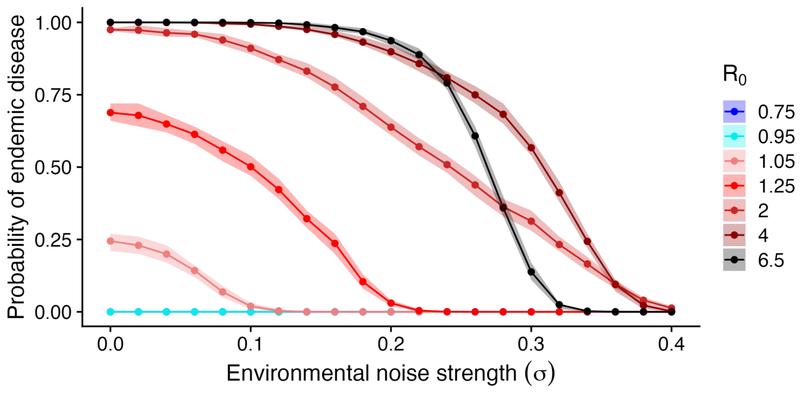
Results

R_0=1.25 | **Deterministic** | **Demographic noise** | **Demographic & Environmental noise (σ=0.12)**



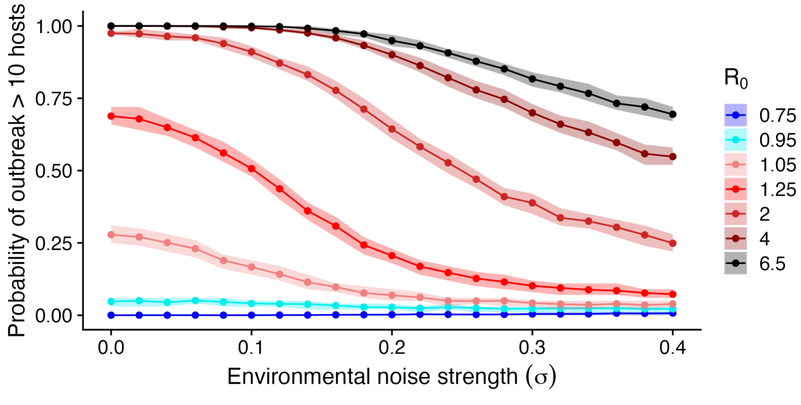
Probability of endemic disease by environmental noise strength

- R_0<1: No endemic disease
- R_0>1: Increased environmental noise strength reduces the probability of endemic disease
- No endemic disease with environmental noise strength > 0.4



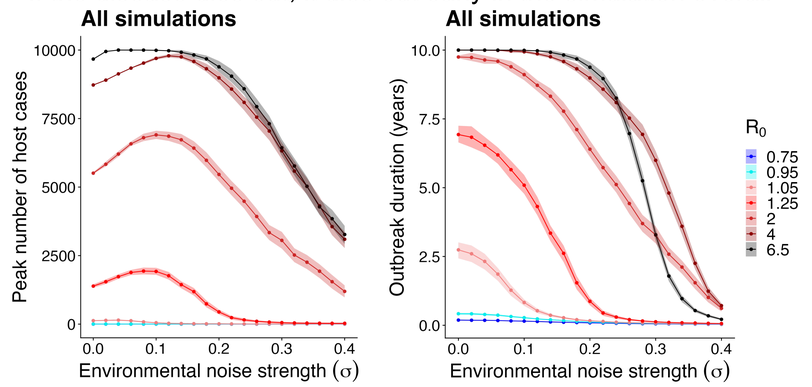
Probability of an outbreak by environmental noise strength

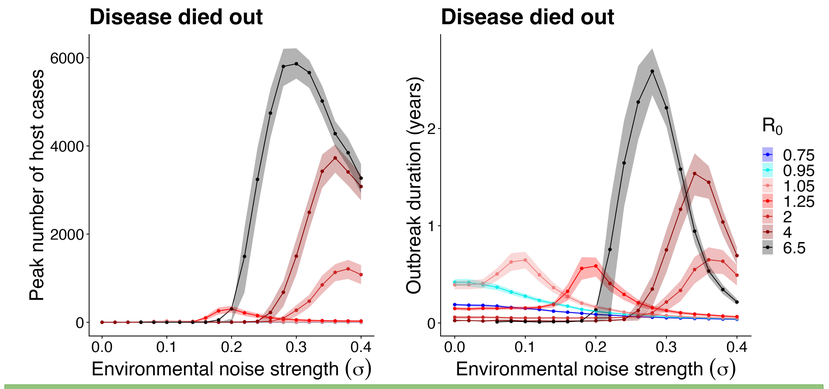
- R_0<1-Slight chance of small outbreak when R_0 is close to 1
- R_0>1-Increased environmental noise strength reduces the probability of an outbreak



Peak cases & outbreak duration by environmental noise strength

- More cases present with higher R_0 and intermediate noise levels
- If the disease dies out, it dies out early in the simulation overall





Conclusions

1. Noise introduces uncertainty; R_0 insufficient to predict outcomes:
   - R_0<1: no endemic disease and low outbreak probability
   - R_0>1: endemic disease and outbreaks are uncertain
2. If mosquito-borne disease transmission parameters respond to environmental variation, then climate variability may yield:
   - R_0<1: low potential for small outbreaks when R_0 is close to 1
   - R_0>1: reduced endemic disease and outbreak probabilities at high noise levels; but outbreak severity peaks at intermediate noise levels

Future directions include sensitivity analyses to determine the influence of each parameter on outcomes and an exploration of noise impacting individual parameters e.g. biting and mortality rate.

Acknowledgements/Literature Cited

Support for this research was provided by the National Science Foundation (grant #1659683) through the Population Biology of Infectious Diseases Undergraduate Research program.

- Mordecai et al. (2019). Thermal biology of mosquito-borne disease. *Ecology Letters*.
- Smith et al. (2012). Ross, Macdonald, and a Theory for the Dynamics and Control of Mosquito-Transmitted Pathogens. *PLOS PATHOGENS*.