Managing White-nose Syndrome in Bats: A Spatially Dynamic Modeling Approach

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Abstract

White-nose syndrome (WNS) is a rapidly spreading fungal disease that has caused unprecedented mass mortality among hibernating North American bat populations. Many control strategies are in development, but nothing is known about the impact of seasonal bat dispersal on those potential interventions. We study the spatial dynamics of WNS by posing and analyzing a two-patch model that incorporates five promising WNS treatment methods. We find that optimum management decisions must take interpopulation movement into account, and show that the effects of dispersal depend on both the control combination and the primary mode of disease transmission.

Background

- WNS is caused by the fungus *Pseudogymnoascus destructans (Pd)*
- Disrupted hibernation patterns in infected bats lead to depletion of fat storage, starvation, and ultimately mortality
- Over 90% mortality has been observed in WNS-affected populations
- Mathematical models can be used to explore the efficacy of management strategies (controls)
- Bats are known to migrate between populations, but previous studies only considered controls in a single hibernaculum
- How does bat dispersal affect newly proposed controls?

Control Strategies

Fungicide (F):	$(1-\alpha)K_{Pd}$
Microclimate (M):	$(1-\alpha)\delta$
Soil Bacteria (B):	$(1-\alpha)\eta, (1-\alpha)\tau$
Ultraviolet Light (UV):	$-\alpha P, (1-\alpha)\tau, (1-\alpha)\delta$
Vaccination (V):	$-\alpha S$

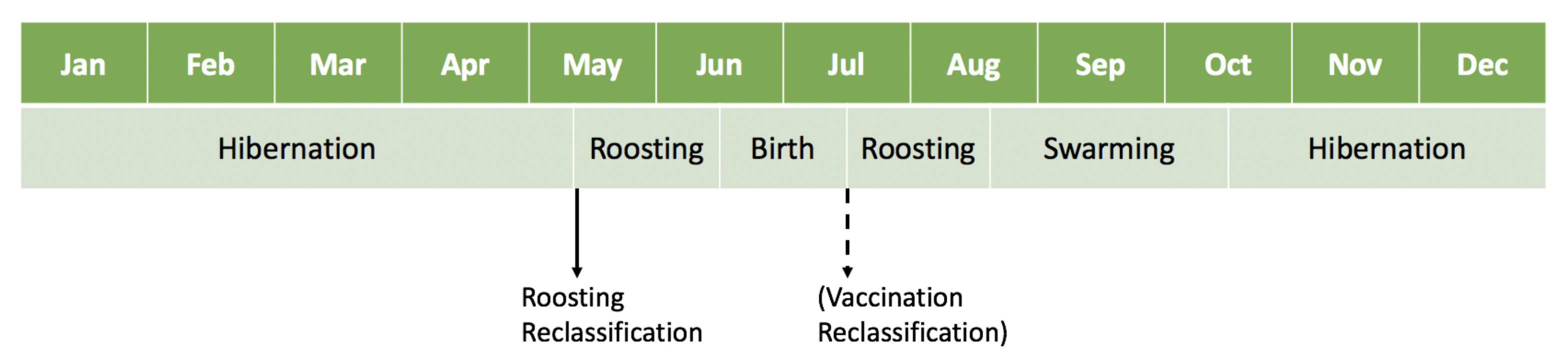
Selected Bibliography

[1] Meyer A, Stevens D, Blackwood J (2016) Predicting Bat Colony Survival Under Controls Targeting Multiple Transmission Routes of White-nose Syndrome. *Journal of Theoretical Biology* 409:60-69.

[2] Norquay KJO, Martinez-Nuñez F, Dubois JE, Monson KM, Willis CKR (2013) Long-distance Movements of Little Brown Bats (Myotis lucifugus). *Journal of Mammalogy* 94(2):506-515.

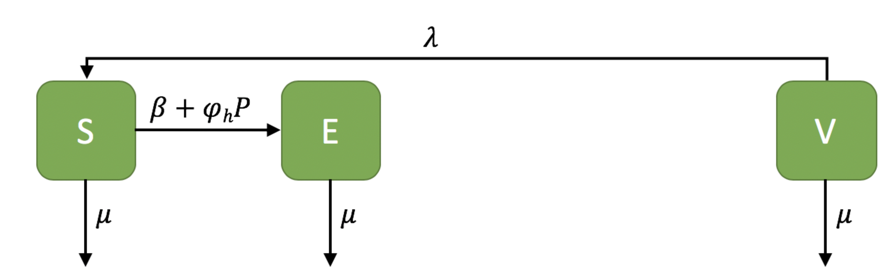
[3] Reynolds HT, Ingersoll T, Barton HA (2015) Modeling the Environmental Growth of Pseudogymnoascus destructans and its Impact on the White-nose Syndrome Epidemic. *Journal of Wildlife Diseases* 51(2):318-331.

Model Overview



- Simulations begin with 1 exposed bat introduced into a subpopulation of 14,999 susceptible bats
- Subpopulations A and B are modeled autonomously
- Free-living *Pd* is modeled logistically with natural growth rate η

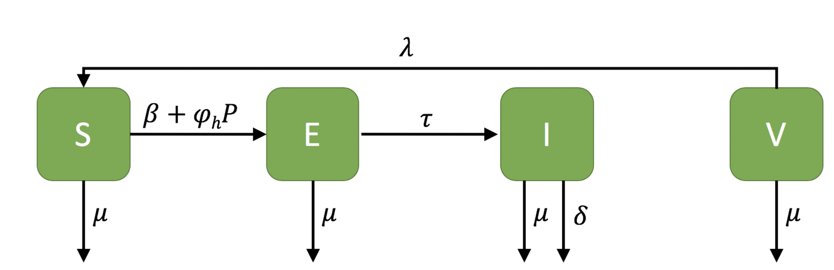
Swarming Phase:



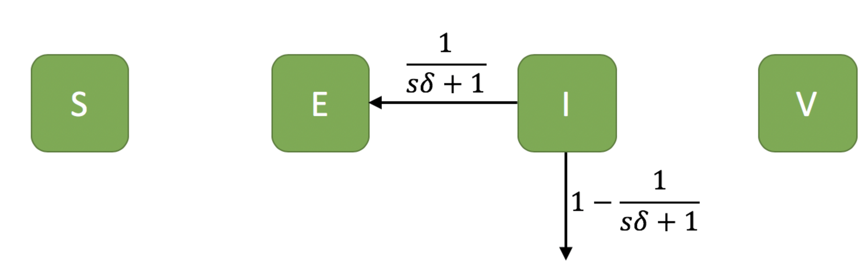
Dispersal Reclassification:

$$\begin{pmatrix} S_{A_1} & E_{A_1} & I_{A_1} \\ S_{B_1} & E_{B_1} & I_{B_1} \end{pmatrix} = \begin{pmatrix} 1-\sigma & \sigma \\ \sigma & 1-\sigma \end{pmatrix} \begin{pmatrix} S_{A_0} & E_{A_0} & I_{A_0} \\ S_{B_0} & E_{B_0} & I_{B_0} \end{pmatrix}$$

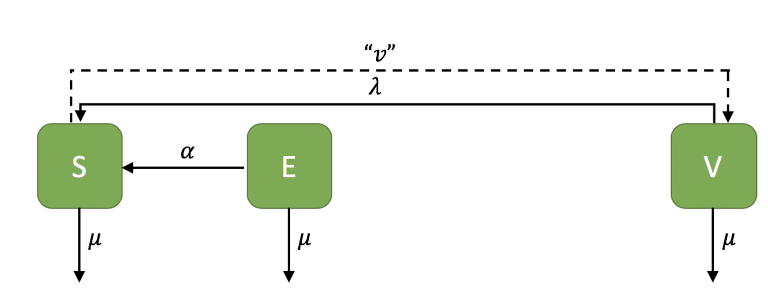
Hibernation Phase:



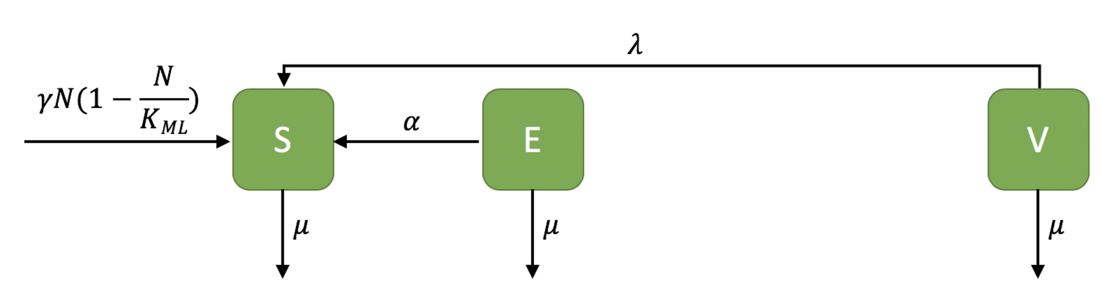
Roosting Reclassification:



Roosting Phase:



Birth Subphase:



Special thanks to my advisor Shandelle M. Henson and the Williams College SMALL REU. Funded by National Science Foundation grant DMS 1659037.

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Results

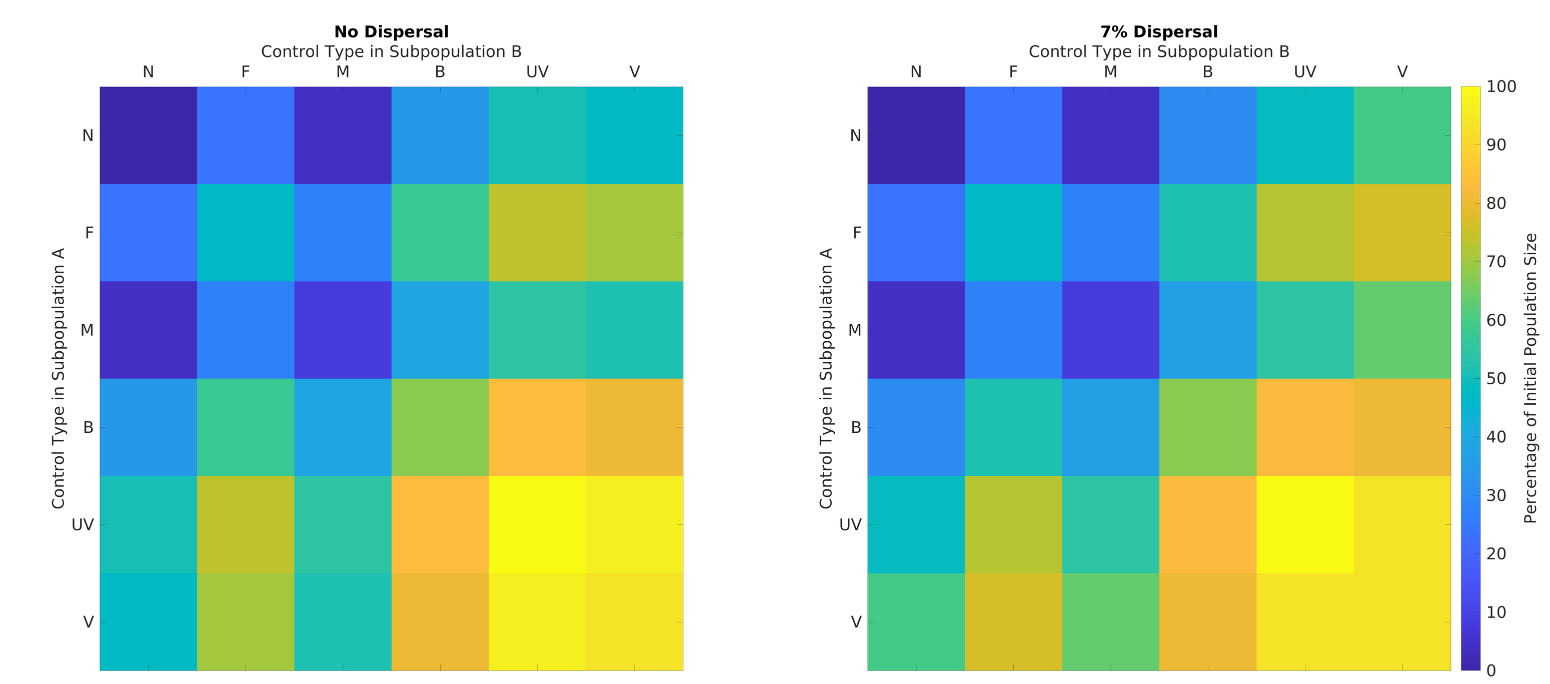

Figure 1: Percent survival after 10 years with no dispersal (left) and 7% dispersal (right). Disease is transmitted equally by environment-to-bat and bat-to-bat contact and the intervention intensity is 90%.

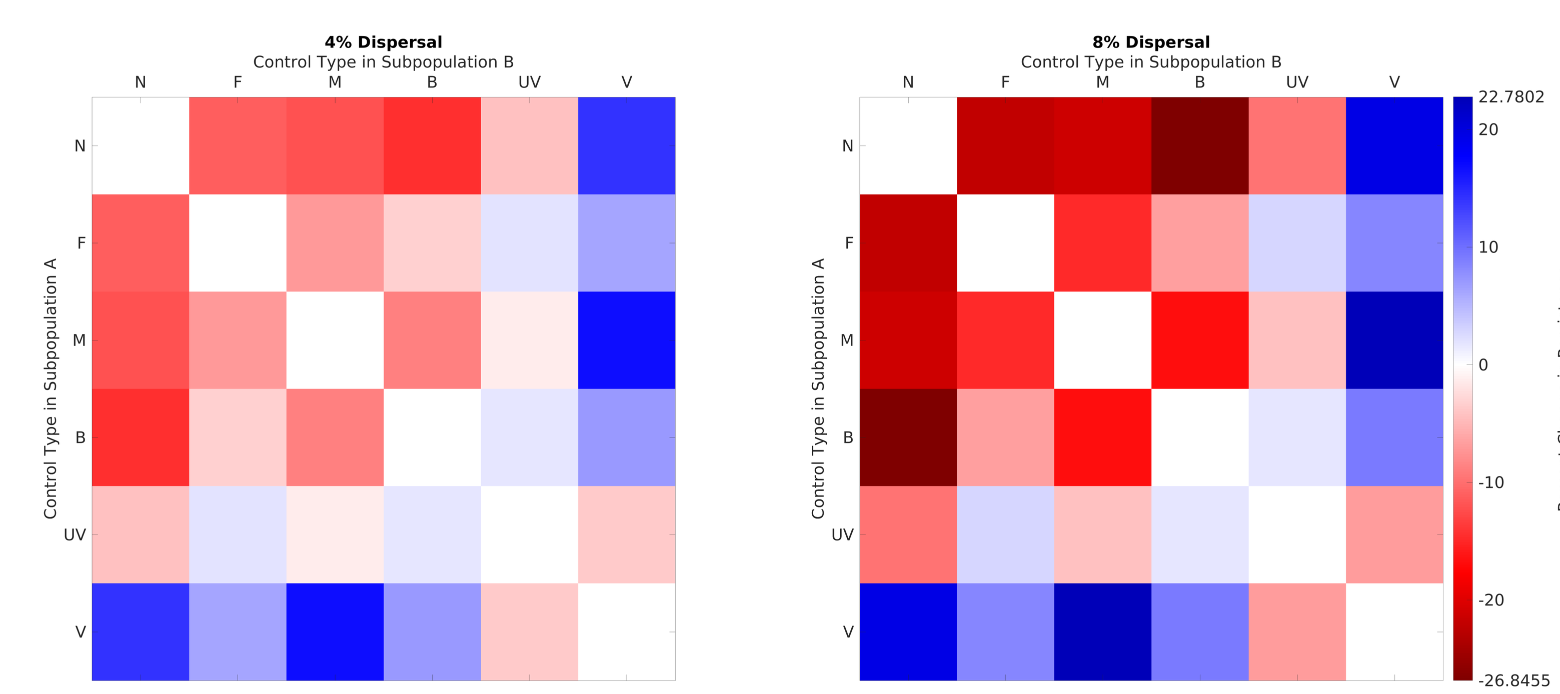

Figure 2: Percent change in 10-year survival between no dispersal and 4% (left) or 8% (right) dispersal. Disease is transmitted primarily by environment-to-bat contact and the intervention intensity is 80%.

Conclusions

- Dispersal can significantly change the expected survival percentages for many combinations of treatment strategies
- Increased dispersal aids the effectiveness of vaccination, but nearly always diminishes the effectiveness of all other controls
- The effects of dispersal depend on the combination of controls, the control intensity, and the route of disease transmission
- Optimal management decisions must take dispersal into account