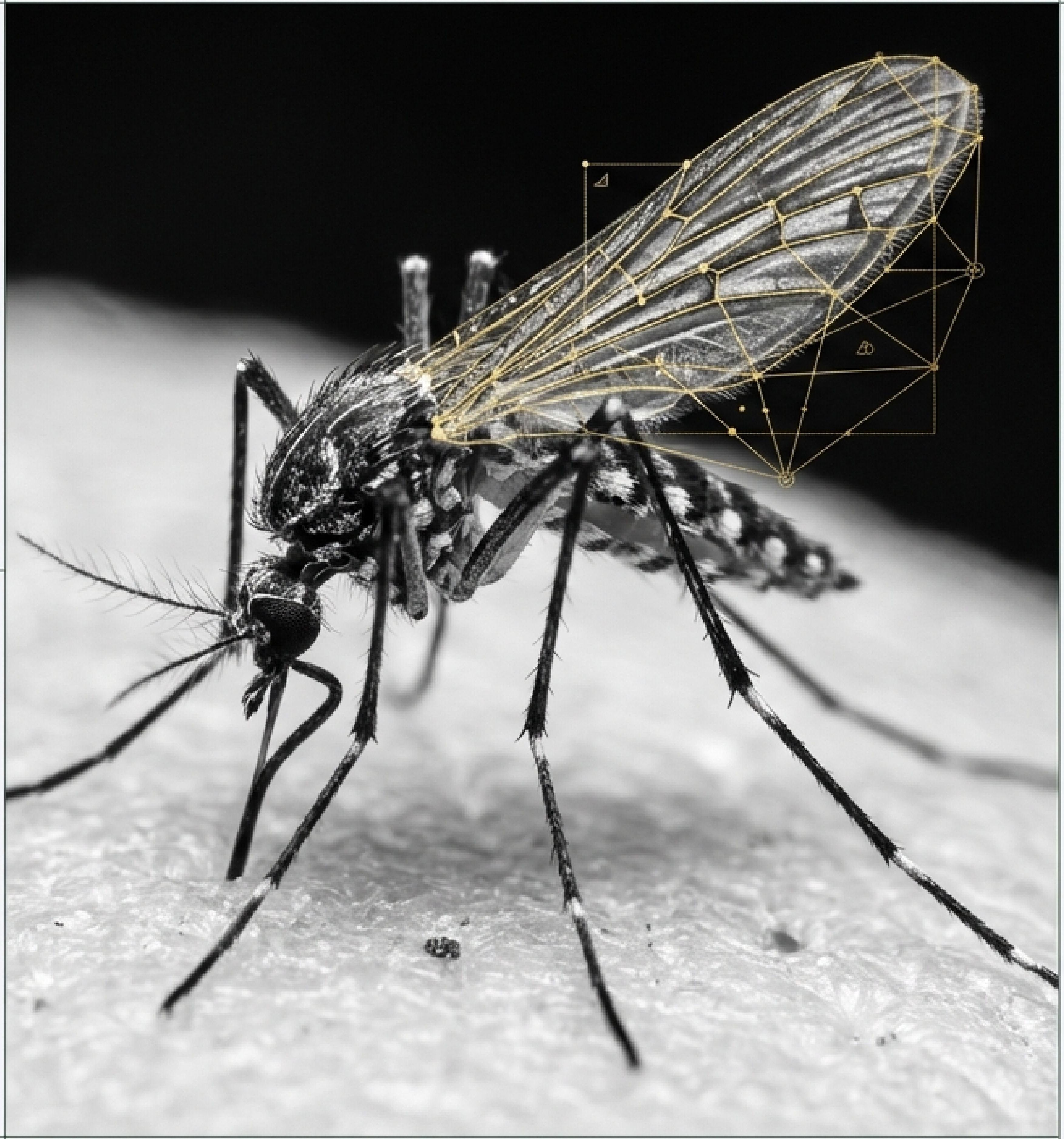
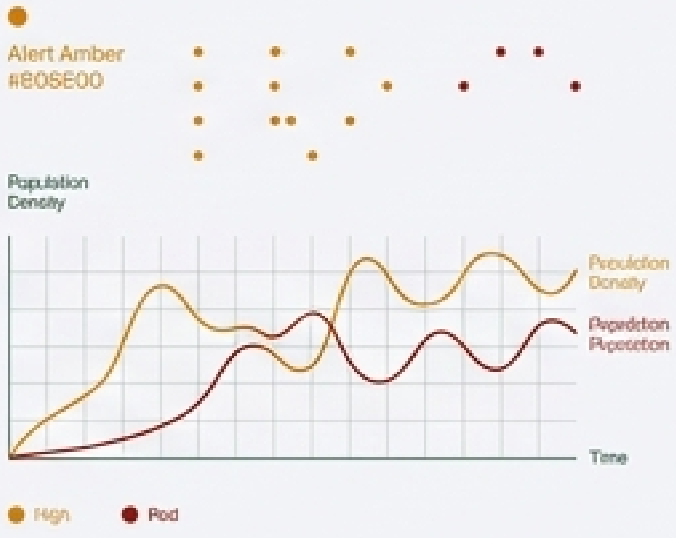
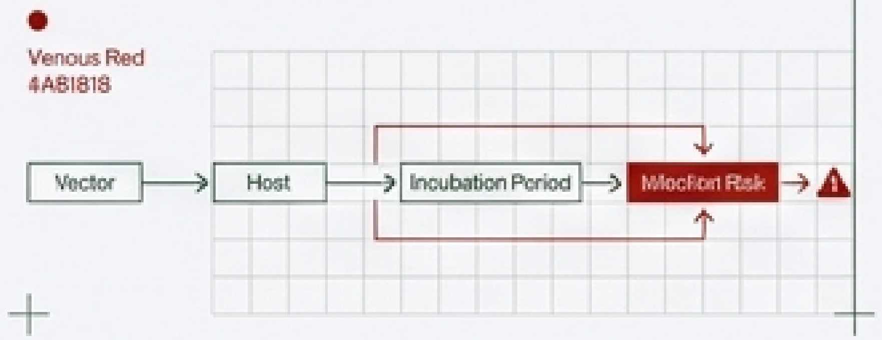


DYNAMICS, DELAYS, AND CONTROL: MATHEMATICAL MODELING OF VECTOR-BORNE DISEASES

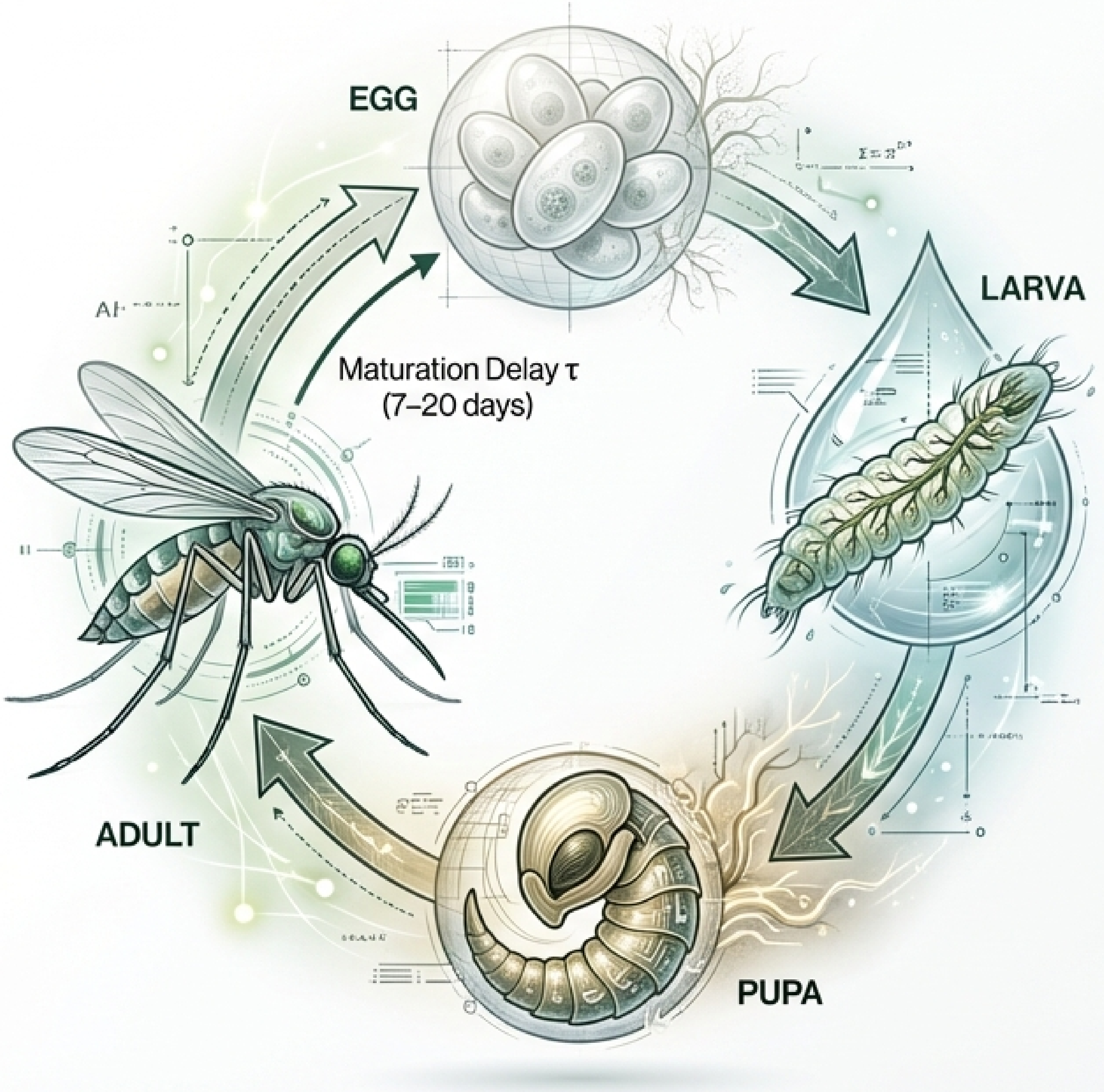
From Mosquito Population Dynamics to Integrated Control Strategies

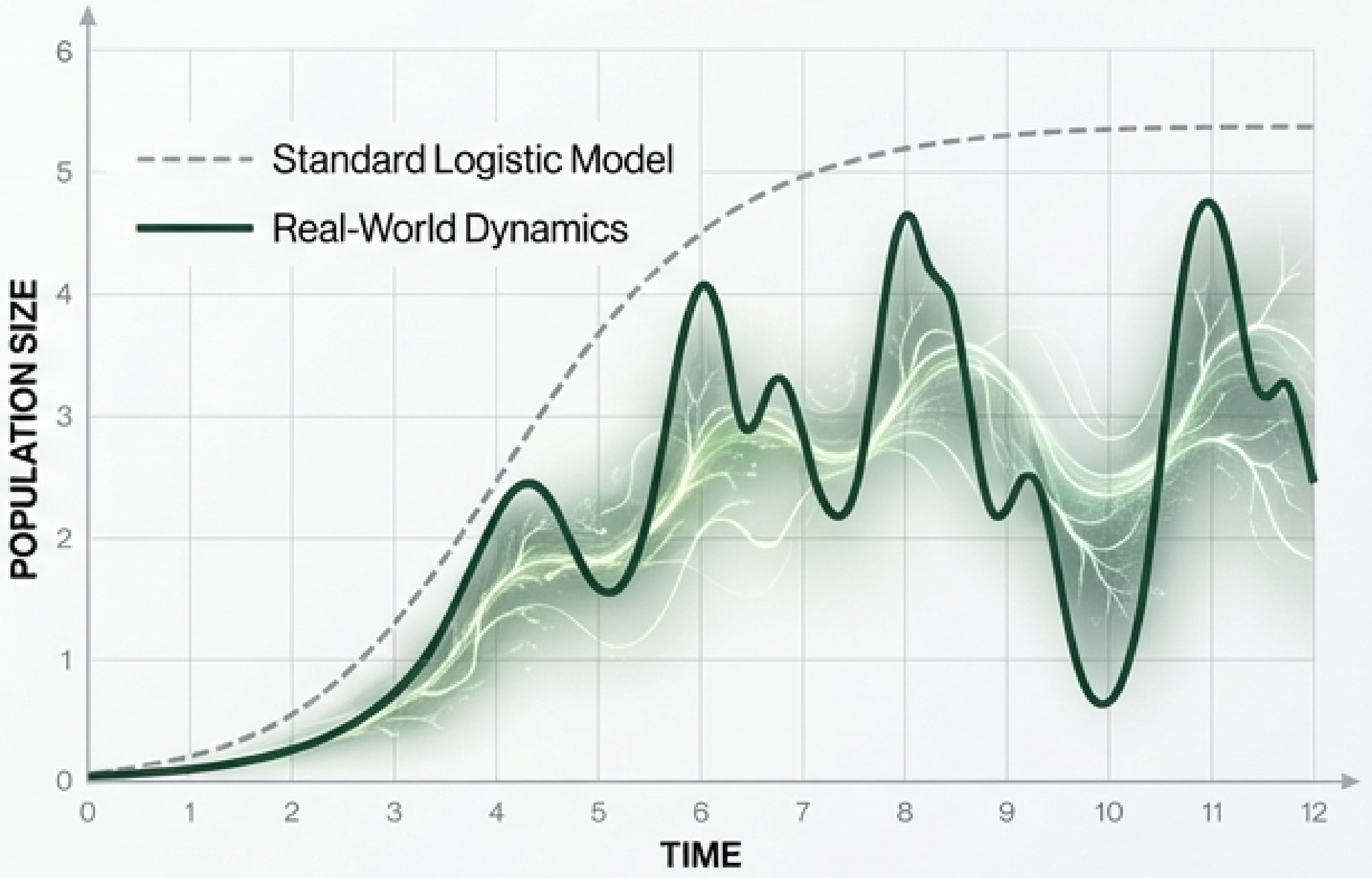




Presented by [Scientist Name]
Department of Mathematics and Statistics

The Complexity of the Vector: Beyond Logistic Growth





Maturation Delay (Temperature Dependent)

Survival Resources (Space/Water)

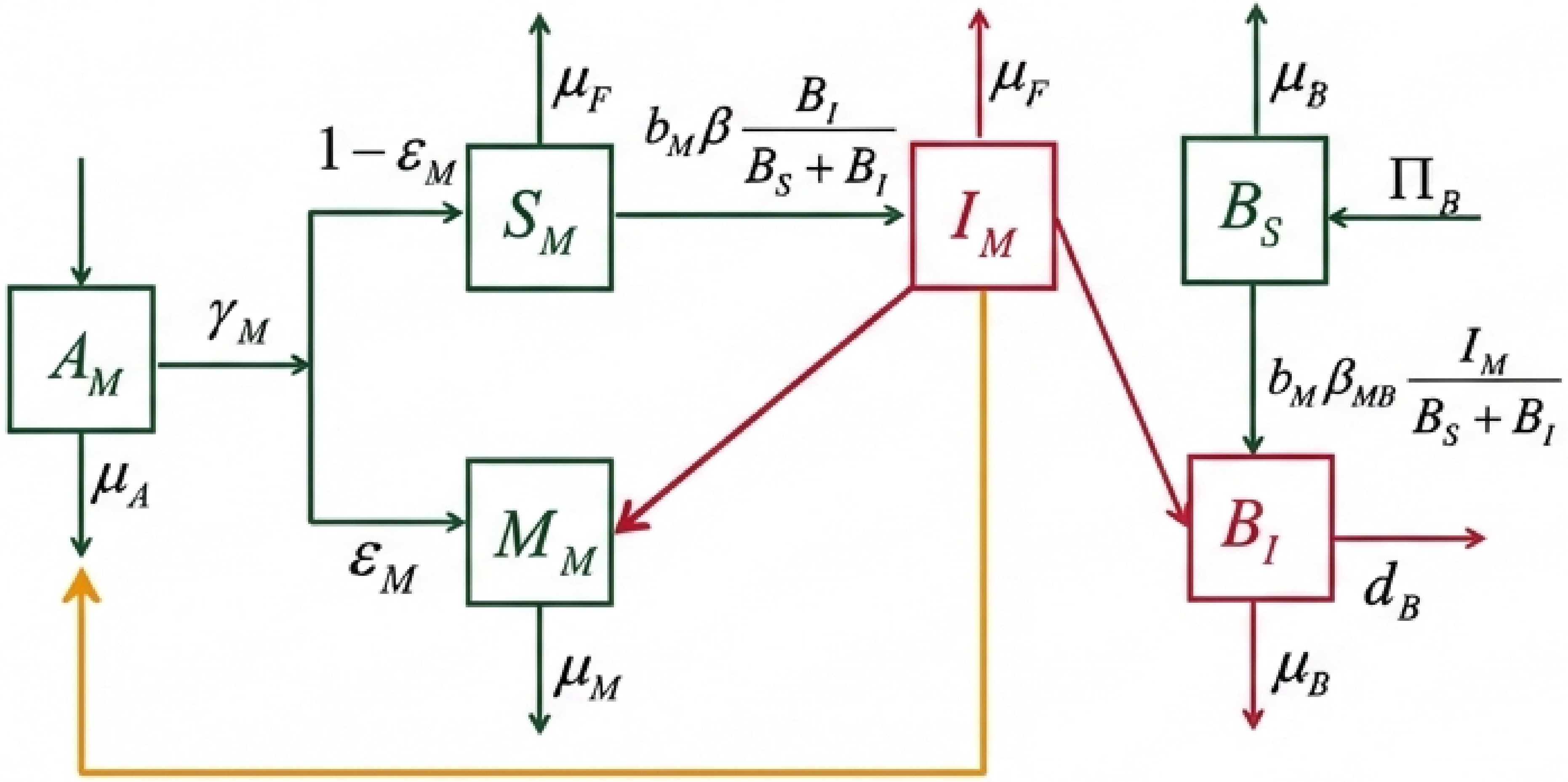
Reproduction Resources (Blood Meals)

Modeling Maturation Delay & Blood Meal Constraints

$$\frac{dM(t)}{dt} = r\underbrace{e^{-\alpha M(t-\tau)}}_{\text{Blood Meal Limitation (Ricker Function)}}\overbrace{M(t-\tau)}^{\text{Population Delay (Time Lag)}}\underbrace{e^{-\mu\tau}}_{\text{Aquatic Survival Probability}} - dM(t) - \kappa M(t)^2$$

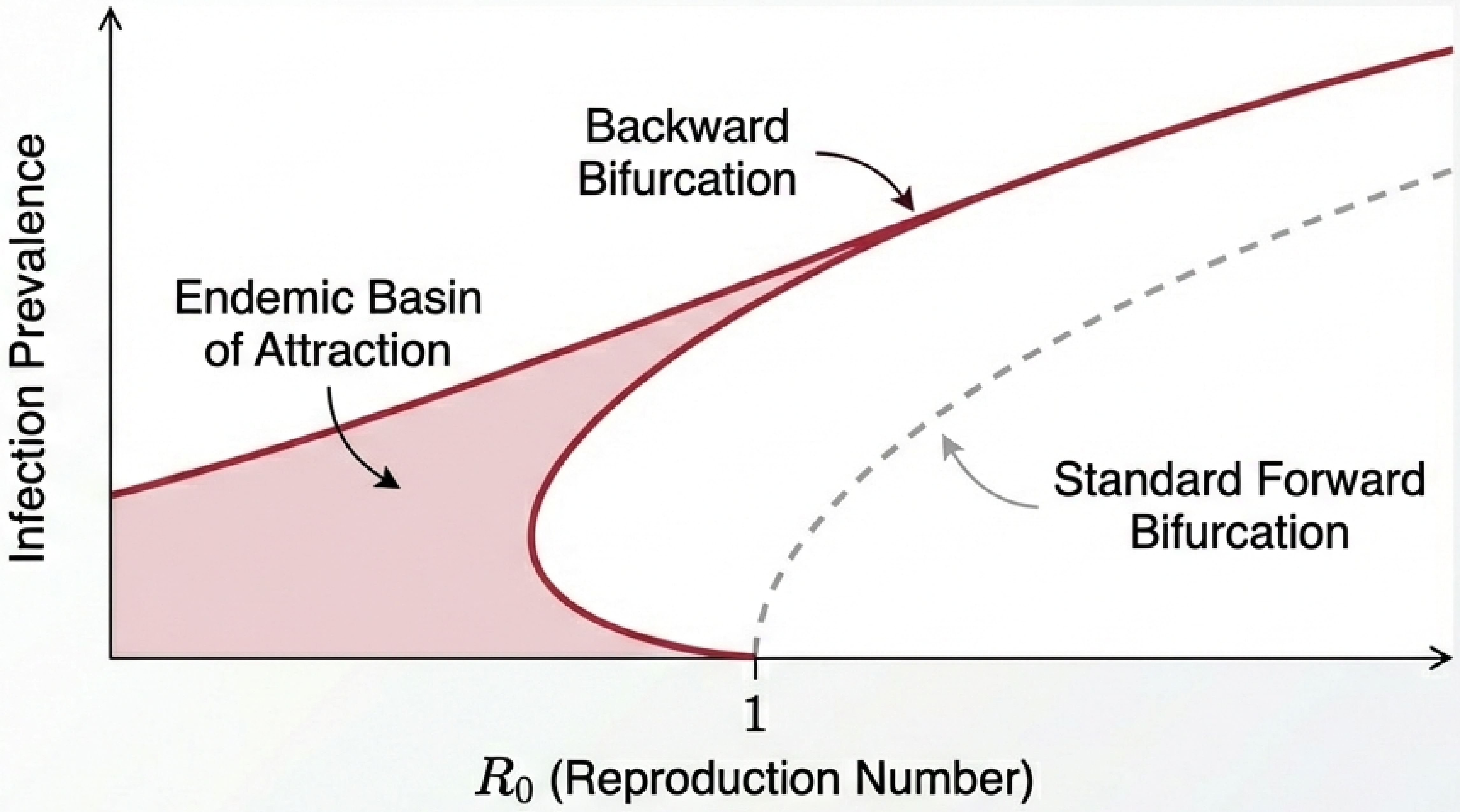
Insight: The interaction between maturation delay (τ) and resource limitation (α) induces Hopf Bifurcations, creating natural population oscillations without external forcing.

West Nile Virus: The Mosquito-Bird Transmission Cycle



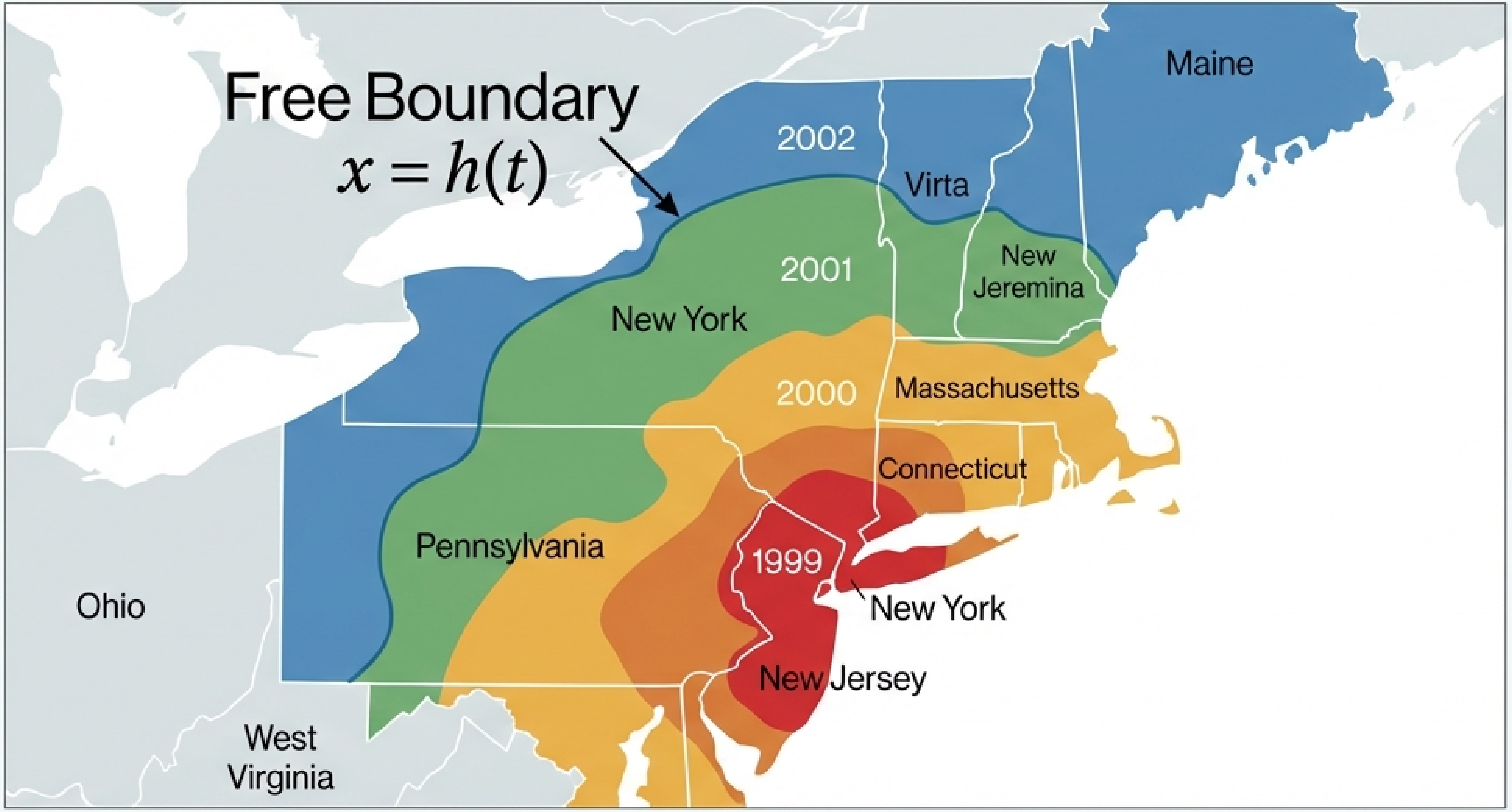
1. **Cross-Infection:** Cycling between Culex vectors and Avian reservoirs (Corvids vs. Non-Corvids).
2. **Vertical Transmission (q):** Infected mothers pass the virus to offspring, allowing WNV to “overwinter” when biting stops.

Threshold Dynamics & Backward Bifurcation



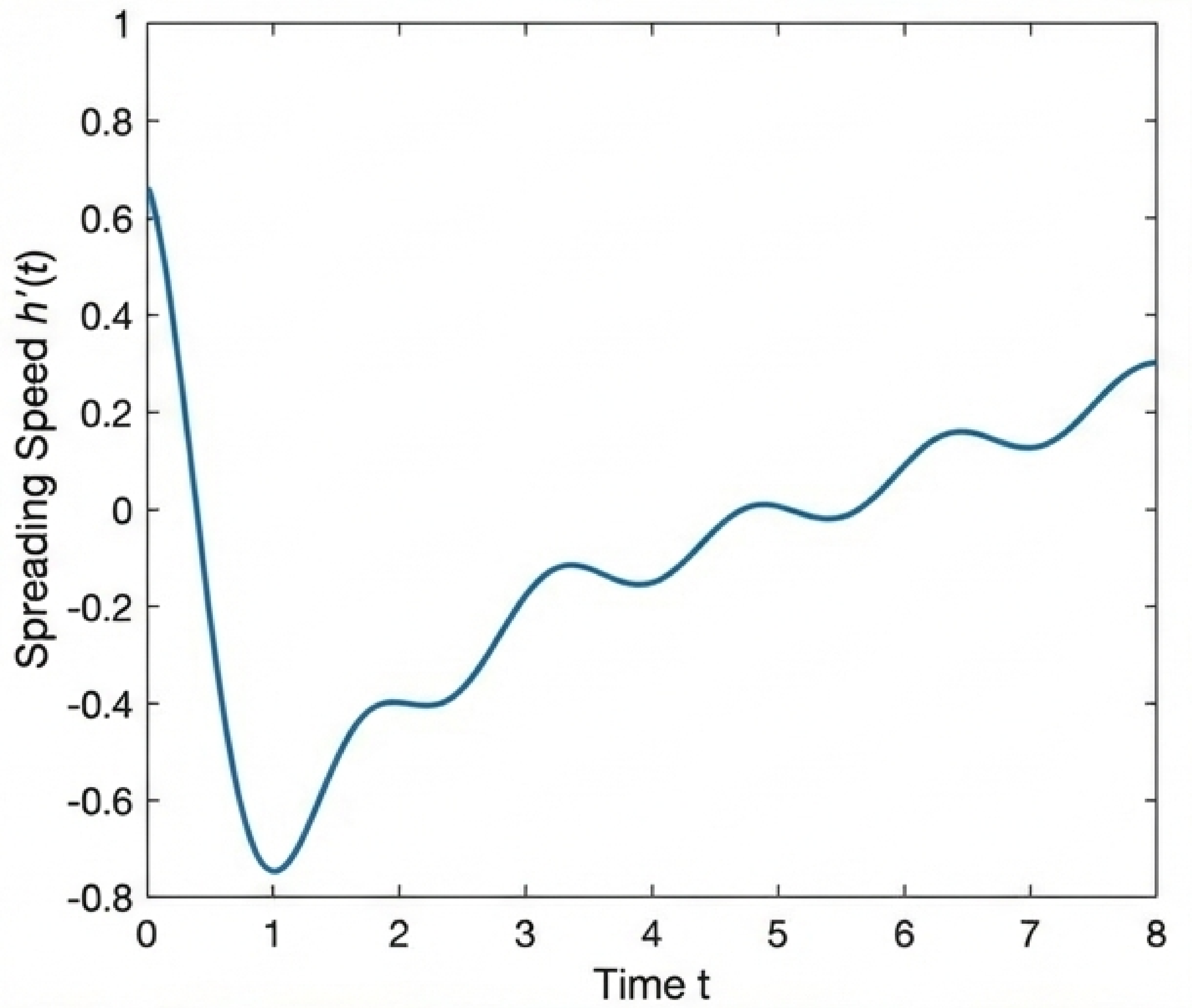
Standard models suggest the disease dies if $R_0 < 1$. Backward bifurcation shows WNV can persist in a stable endemic state even below this threshold, requiring drastic reduction in transmission to eradicate.

Spatial Spreading: A Free Boundary Problem



The infected domain expands expands as a reaction-diffusion system. The boundary $h(t)$ is an unknown function of time, driven by climate warming represented by $a(t, x)$.

The Spreading Speed & Risk Index

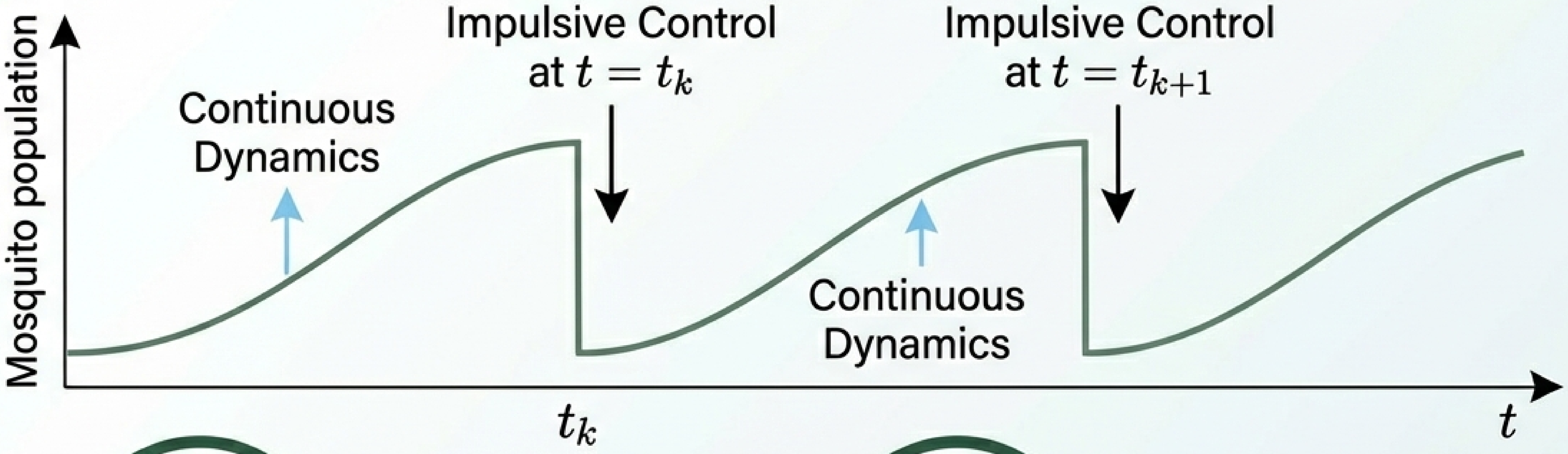


The Spreading-Vanishing Dichotomy

Spatial-Temporal Risk Index: $R_0^F(t)$

- If $R_0^F(t) > 1$, the invasion front accelerates.
- If $R_0^F(t) \leq 1$, the virus range.
- If $R_0^F(t) \leq 1$, the virus range collapses.

Integrated Control: Impulsive Differential Equations



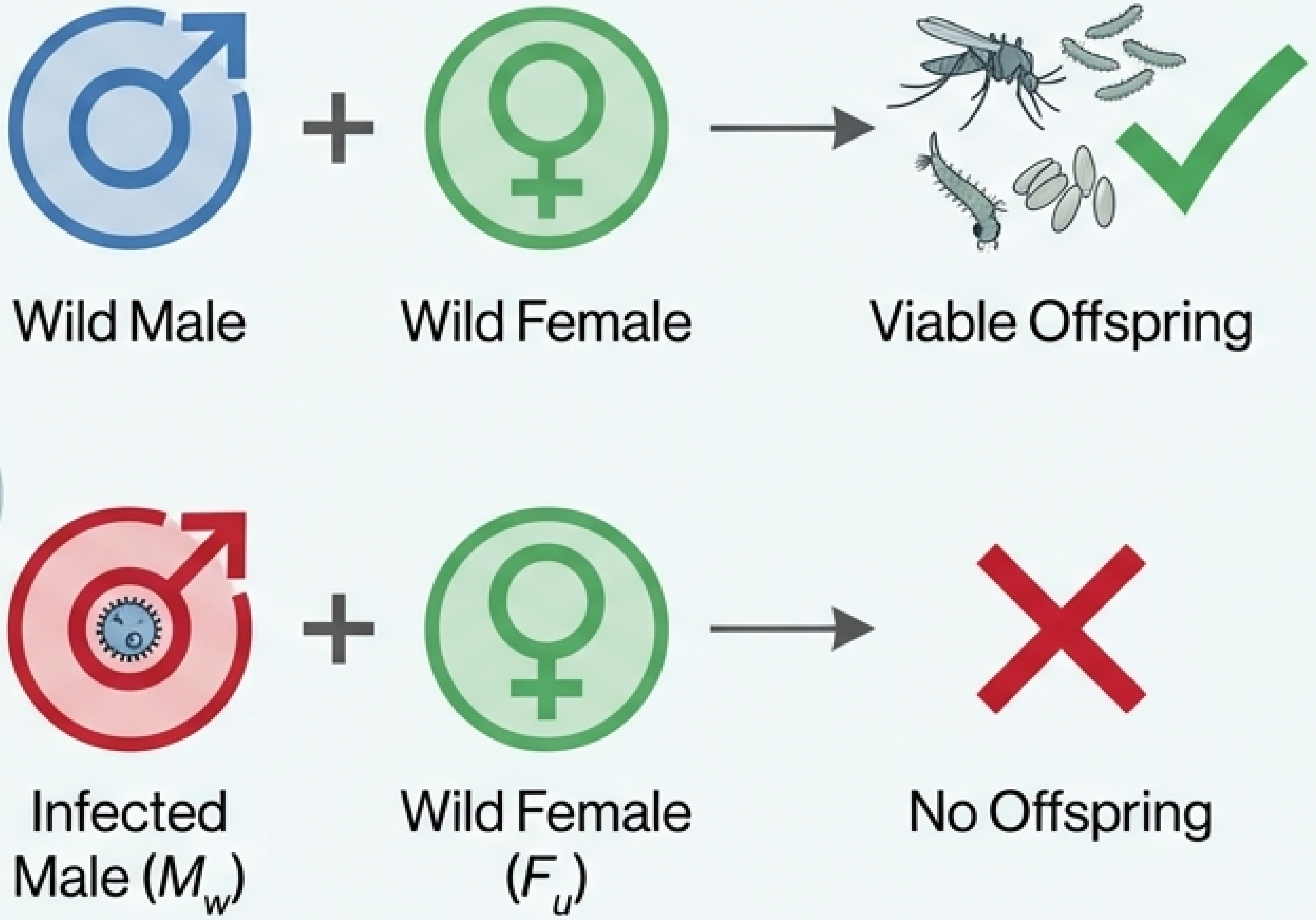
Chemical Insecticide

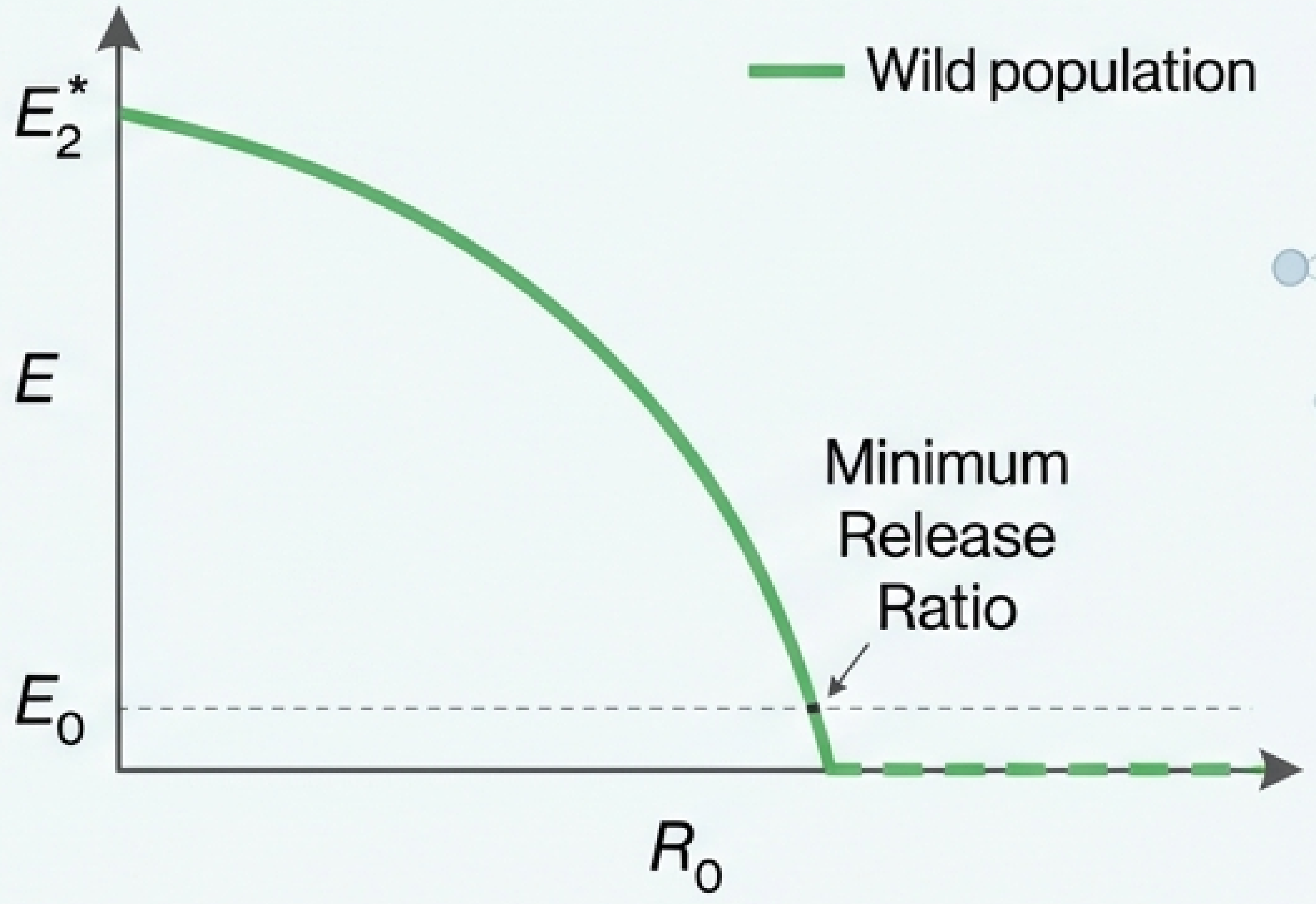
Wolbachia Release

$$F_u(t^+) = (1 - p_1)F_u(t)$$

Wolbachia & Cytoplasmic Incompatibility (CI)

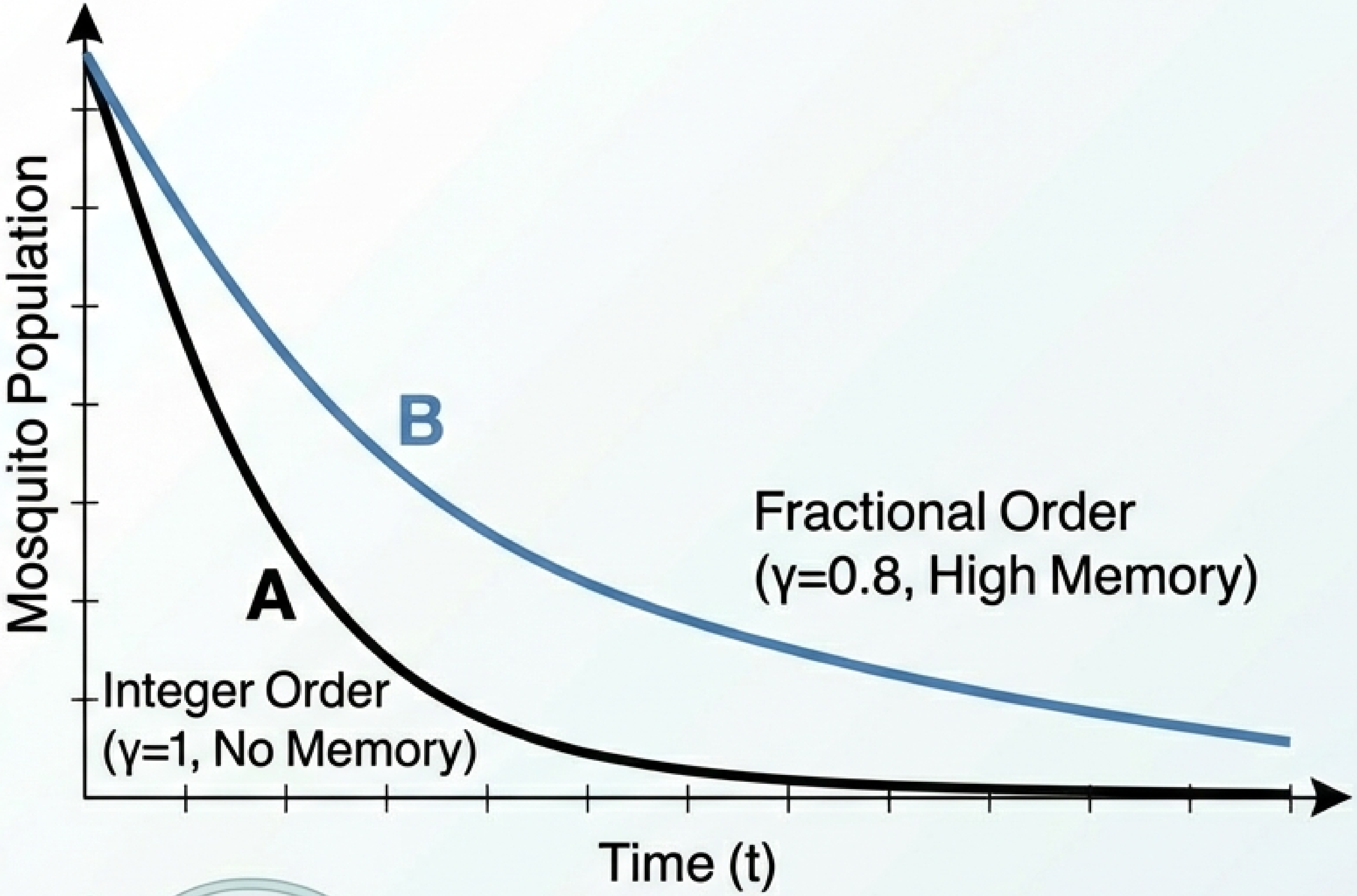
Mating Dynamics





Releasing infected males effectively sterilizes wild females. Success depends on the release ratio exceeding the threshold to crash the population.

The Memory Effect: Fractional-Order Models

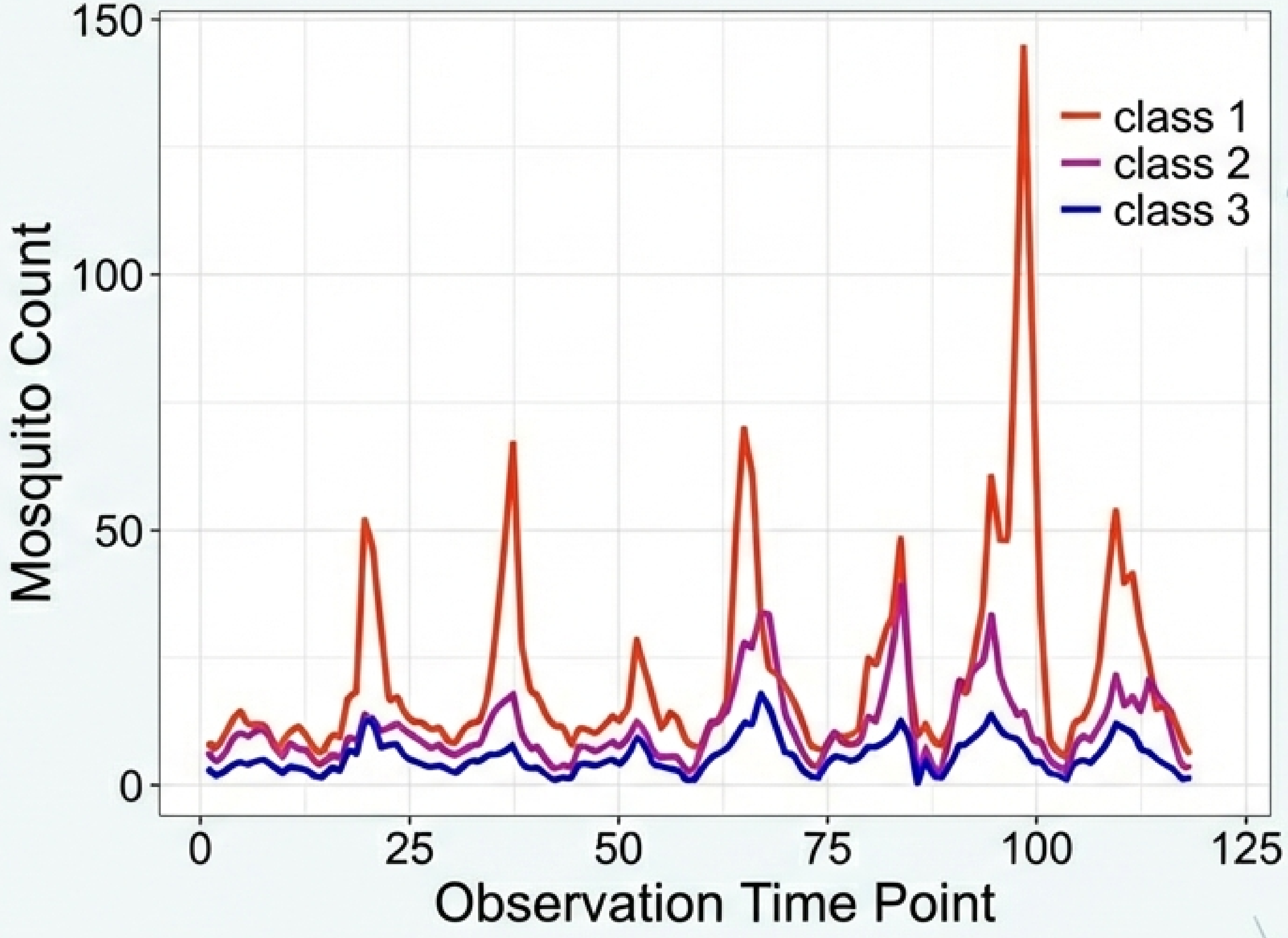


Key Insight: Mosquitoes are not memory-less. Past environmental conditions influence behavior. In low fecundity scenarios, high memory intensity slows down eradication efforts.

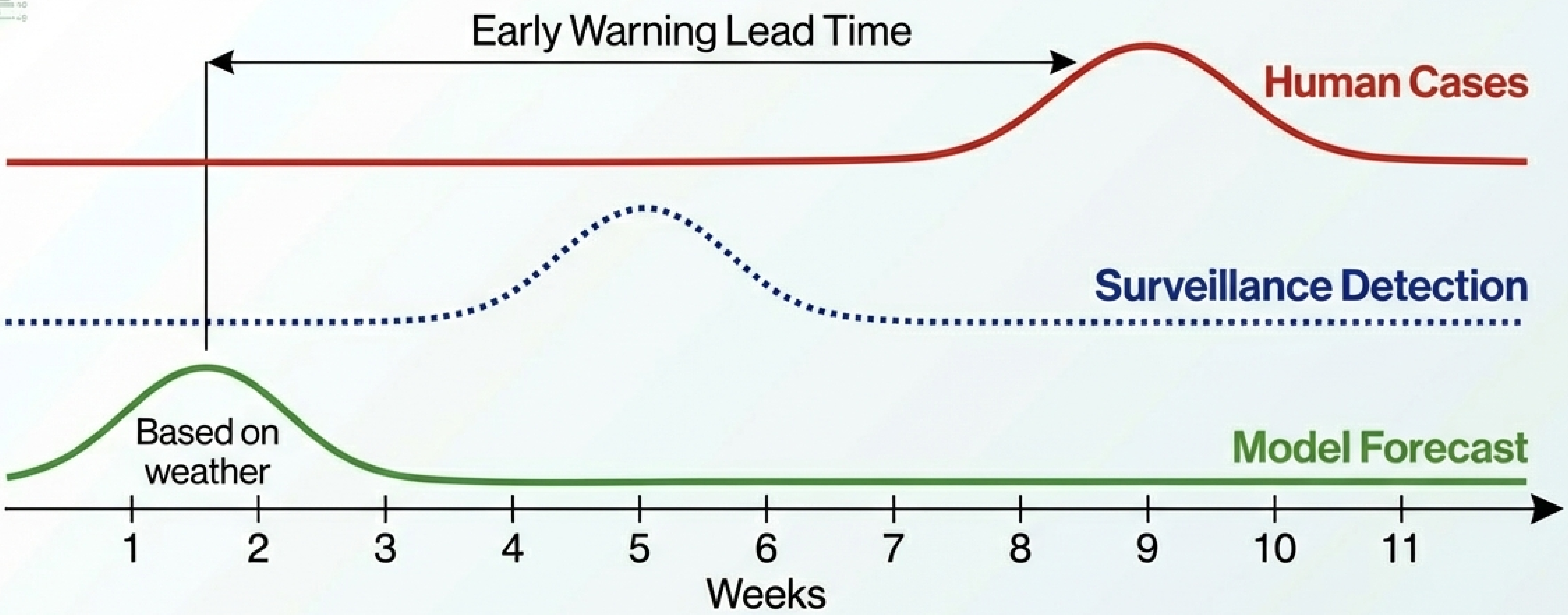
From Theory to Data: The Peel Region Case Study

Data: 9 years of surveillance (2004-2012) from 29 traps in Peel Region, Ontario.

Insight: Clustering reveals heterogeneity. Urban traps behave differently than rural ones due to catch basins and vegetation.

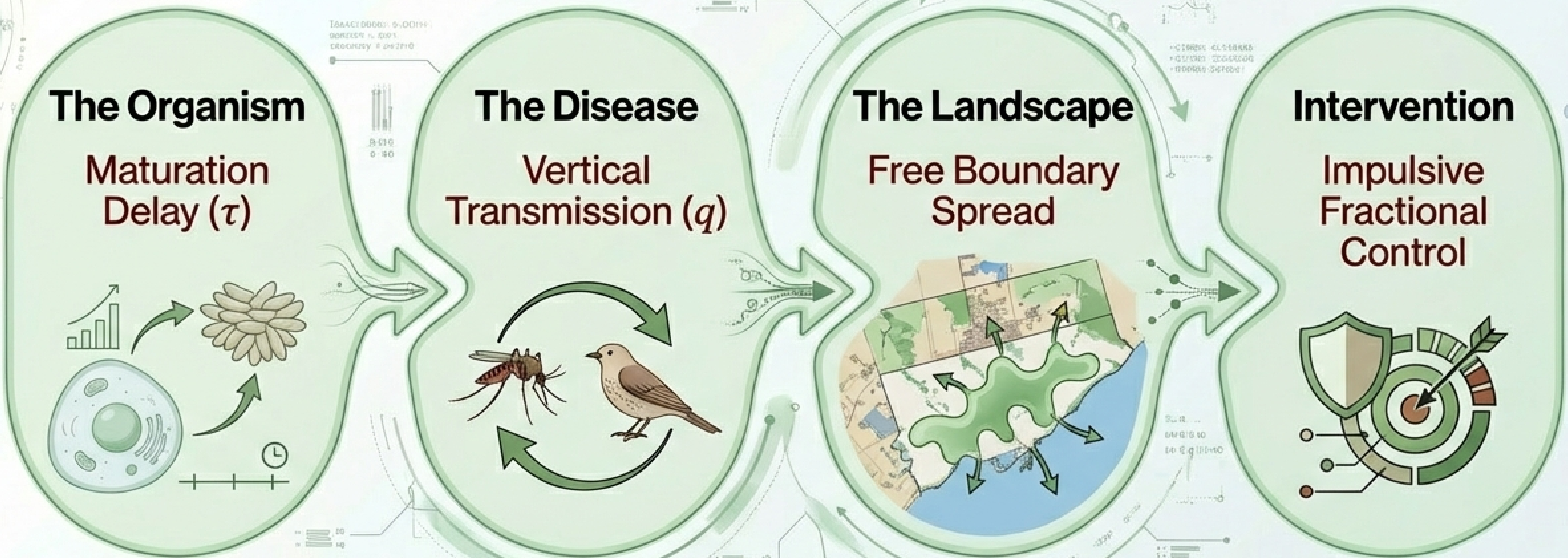


Weather-Based Forecasting & Early Warning



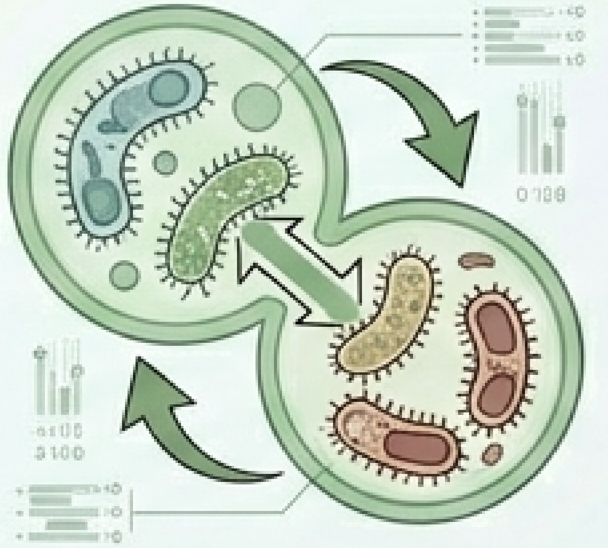
Mixture Markov Regression links daily temperature/rain to cluster behaviors, predicting outbreaks weeks before human cases appear.

Synthesis: The Biological Scale-Up

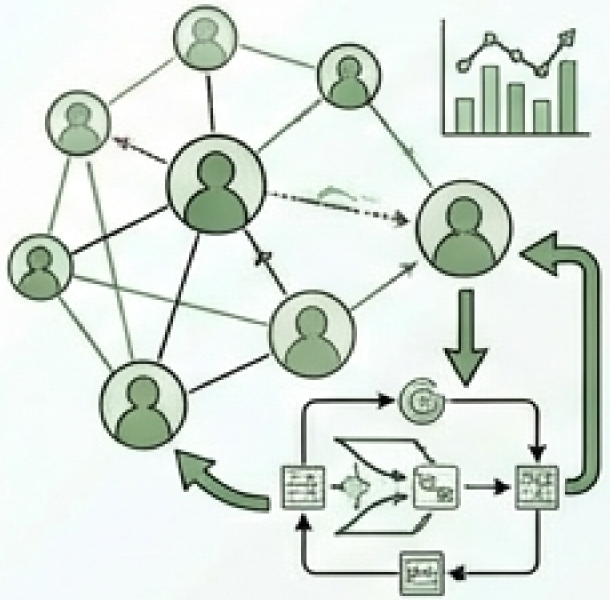


Future Directions & Challenges

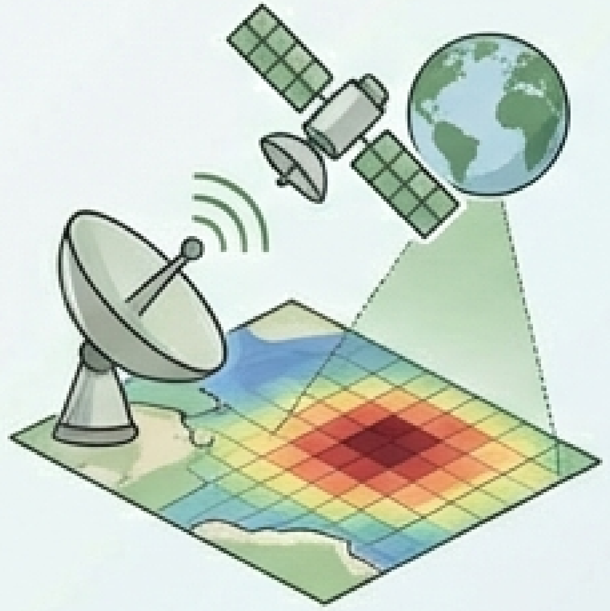
1. Bird Migration: Incorporating directional dispersal into spatial models.



2. Multi-Strain Competition: Modeling interactions between different *Wolbachia* strains.



3. Human Behavior: Coupling epidemic models with human behavioral changes.



4. Data Integration: Real-time
Real-time satellite climate data for boundary conditions.

Mathematical modeling is the bridge between ecological complexity and public health safety.

To defeat vector-borne diseases, our models must evolve as fast as the vectors themselves.

Contact: [Scientist Name] | [Lab/University Name] | [Email Address]