Environmental Stochasticity and Outbreaks in Population Dynamics

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The methodology

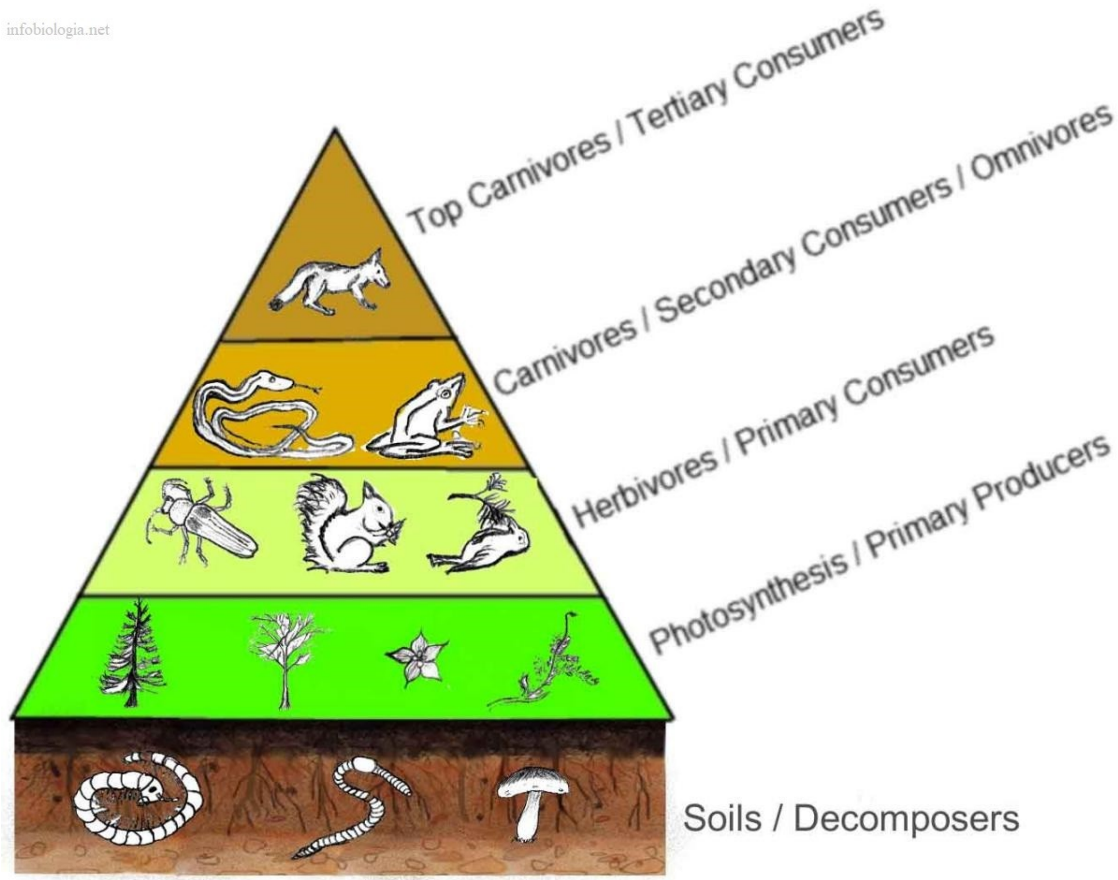
$$x_{n+1} = r\, x_n \left(1 - \frac{x_n}{k}\right)$$

$$\Downarrow$$

$$x_{n+1} = \rho\, r\, x_n \left(1 - \frac{x_n}{k}\right)$$

Heagy et al. (1994), Toniolo et al. (2002), Metta et al. (2010)

Three-species model



Secondary consumers

Primary consumers

Primary producers

Hastings-Powell's model

Primary producers

$$\frac{dx}{dt} = x(1-x) - \frac{a_1 x}{1+b_1 x} y$$

Primary consumers

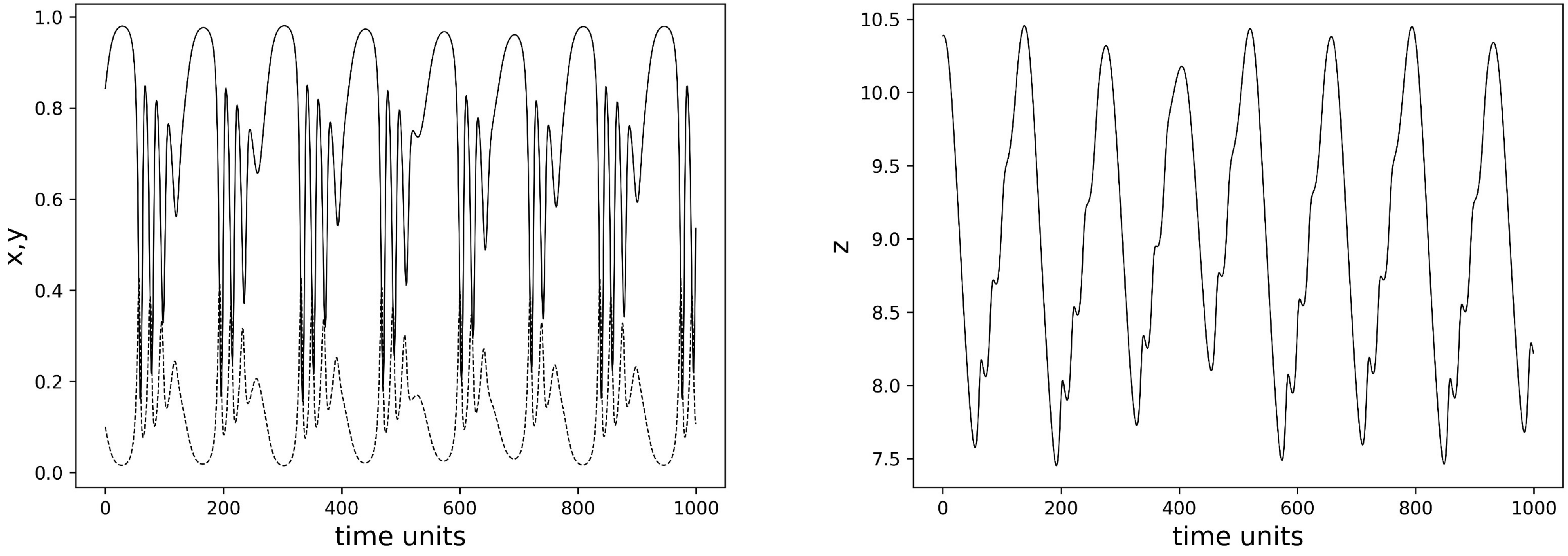
$$\frac{dy}{dt} = \frac{a_1 x}{1+b_1 x} y - \frac{a_2 y}{1+b_2 y} z - d_1 y$$

Secondary consumers

$$\frac{dz}{dt} = \frac{a_2 y}{1+b_2 y} z - d_2 z$$

Vissio Gabriele, Provenzale Antonello (2021), *On-off intermittency in a three-species food chain*, Mathematics, 9(14): 1641.

Hastings-Powell's model



Stochastic intensity of grazing

Primary producers

$$\frac{dx}{dt} = x(1-x) - \frac{a_1 x}{1+b_1 x} y$$

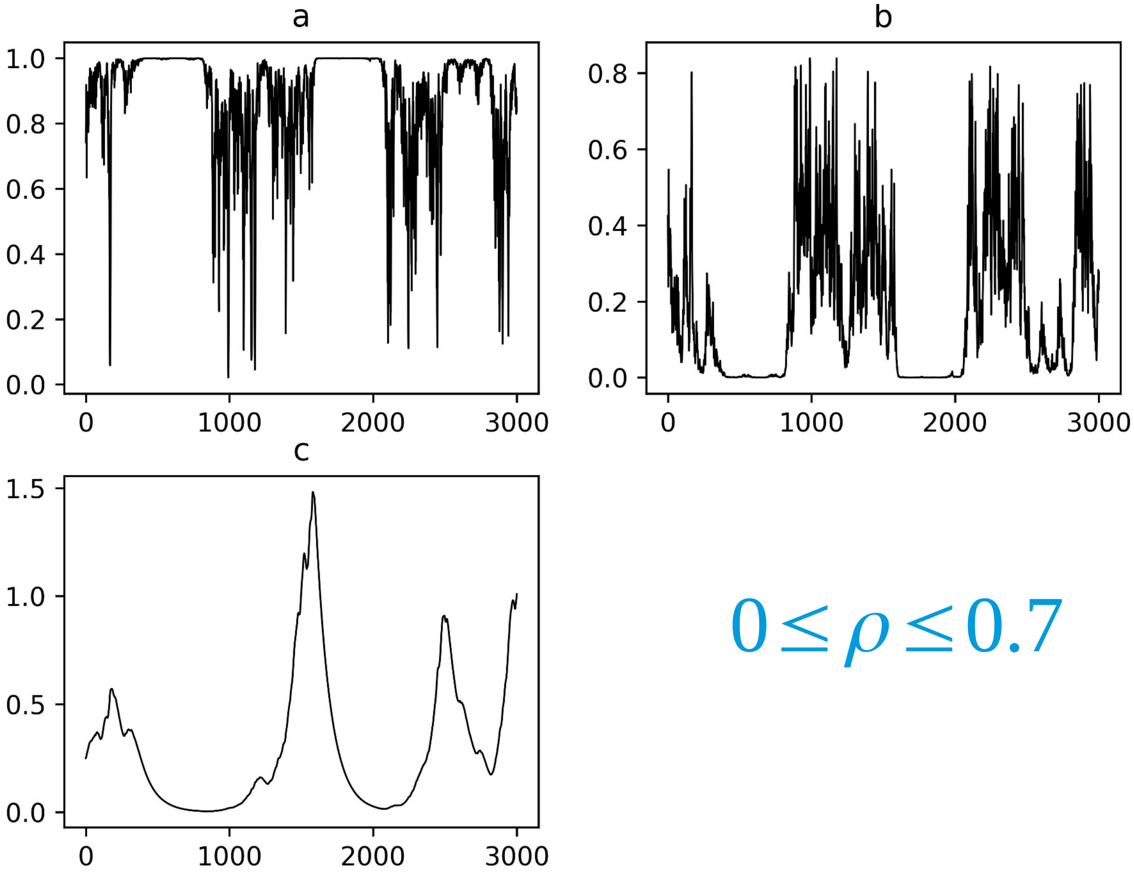
Primary consumers

$$\frac{dy}{dt} = \frac{a_1 x}{1+b_1 x} y - \frac{a_2 y}{1+b_2 y} z - d_1 y$$

Secondary consumers

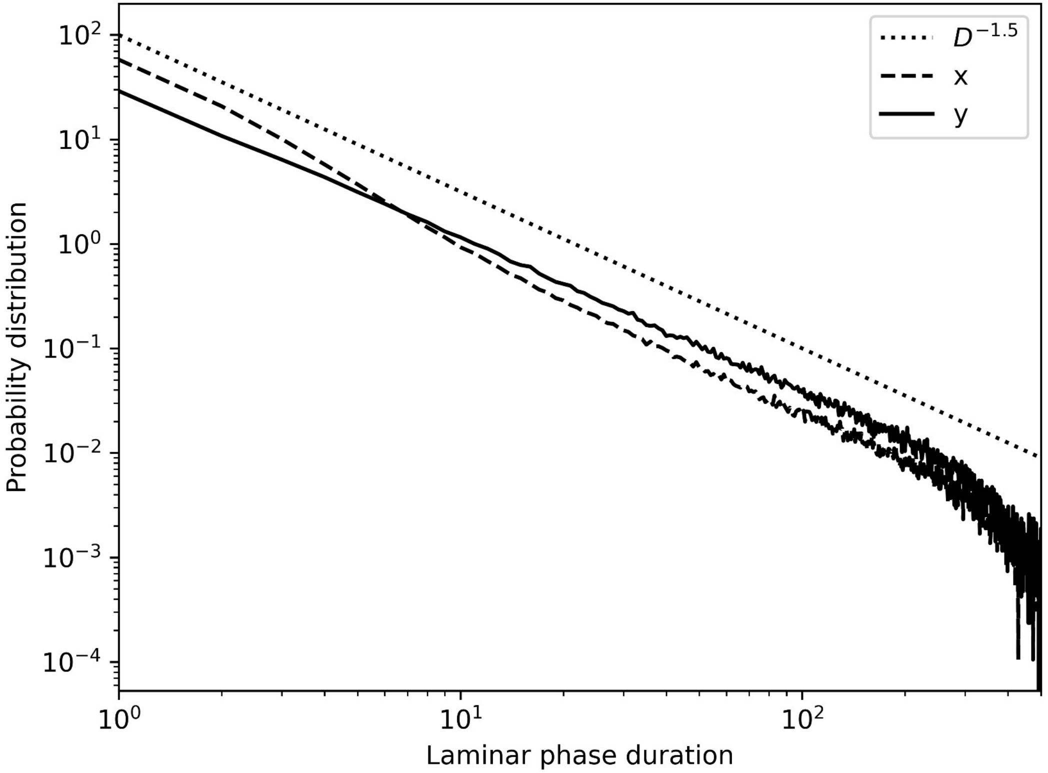
$$\frac{dz}{dt} = \frac{a_2 y}{1+b_2 y} z - d_2 z$$

Stochastic intensity of grazing



$$0 \leq \rho \leq 0.7$$

Stochastic intensity of grazing



On-off intermittency

Alternation between laminar phases and sudden bursts

Duration of laminar phases follows a power law

It could explain population outbreaks

Stochastic carrying capacity

Primary producers

$$\frac{dx}{dt} = x(1-x) - \frac{a_1 x}{1+b_1 x} y$$

Primary consumers

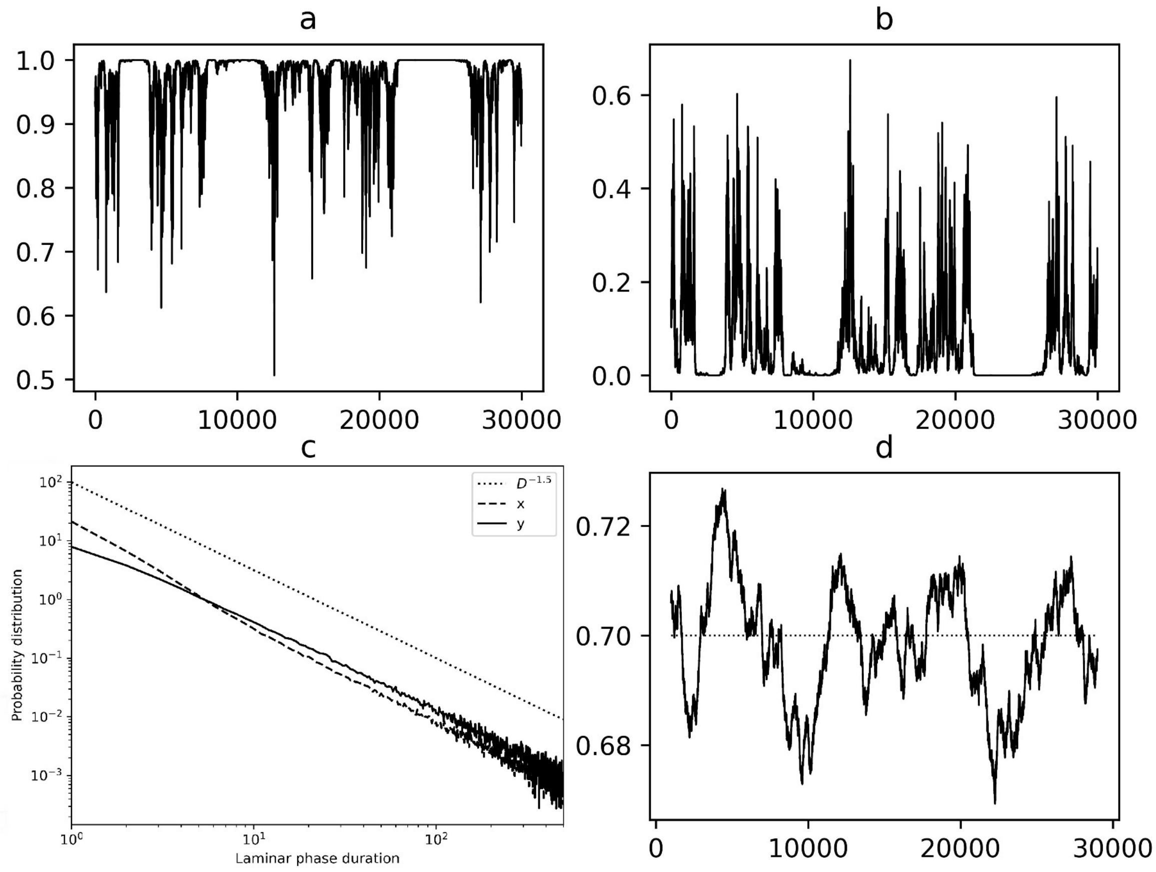
$$\frac{dy}{dt} = \frac{a_1 x}{1+b_1 x} y - \frac{a_2 y}{1+b_2 y} z - d_1 y$$

Secondary consumers

$$\frac{dz}{dt} = \frac{a_2 y}{1+b_2 y} z - d_2 z$$

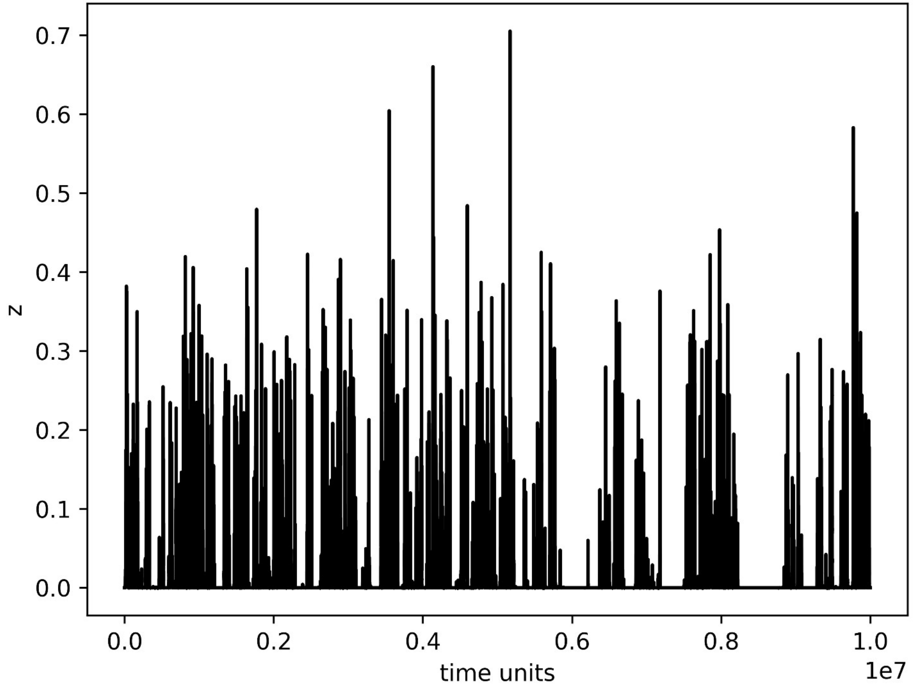
Stochastic carrying capacity

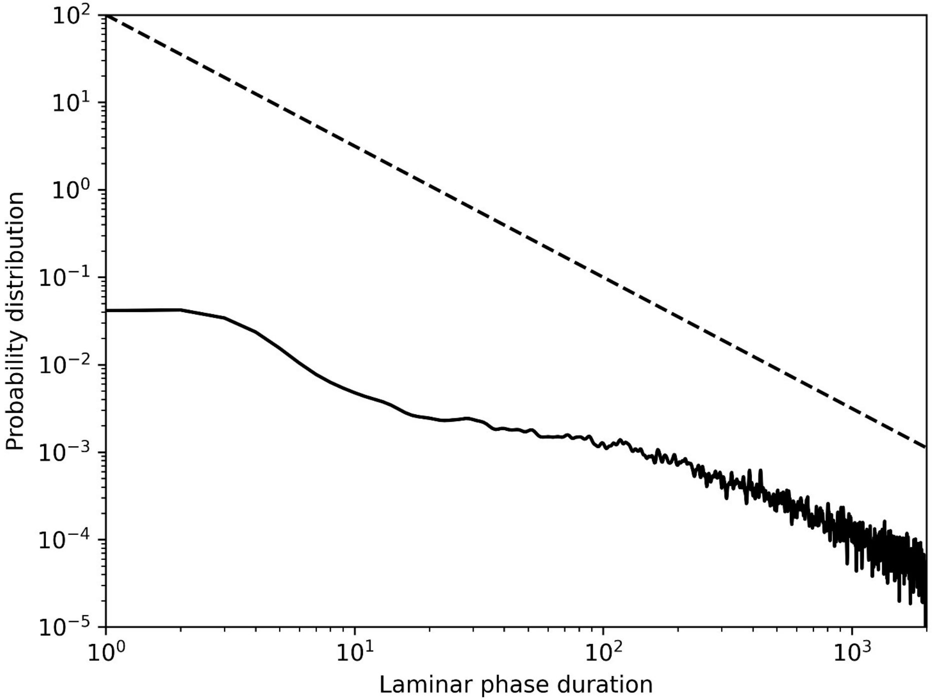
$0 \le \rho \le 1.4$



Stochastic carrying capacity

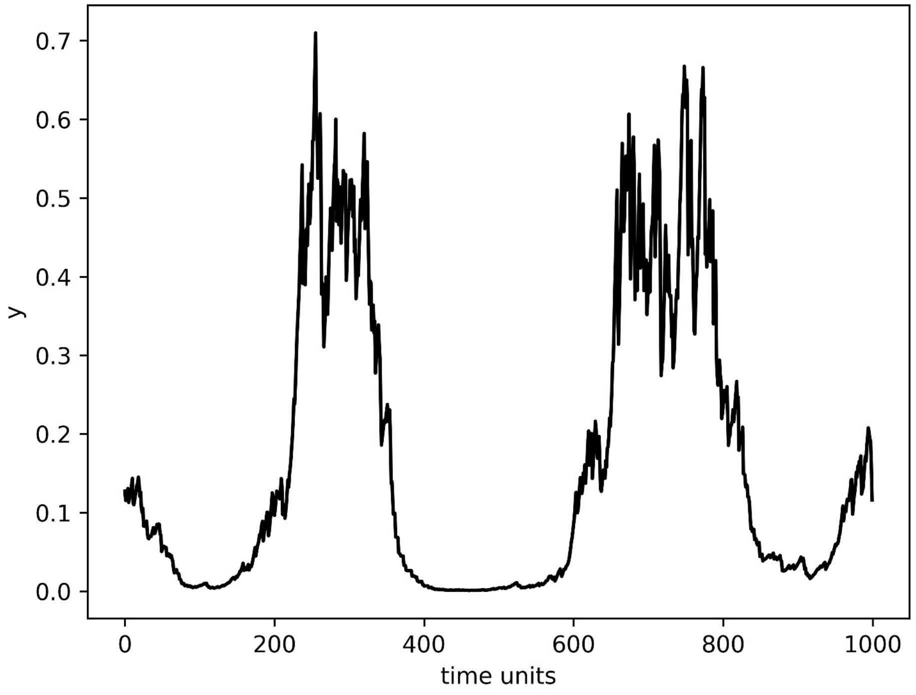
$0 \leq \rho \leq 1.5$

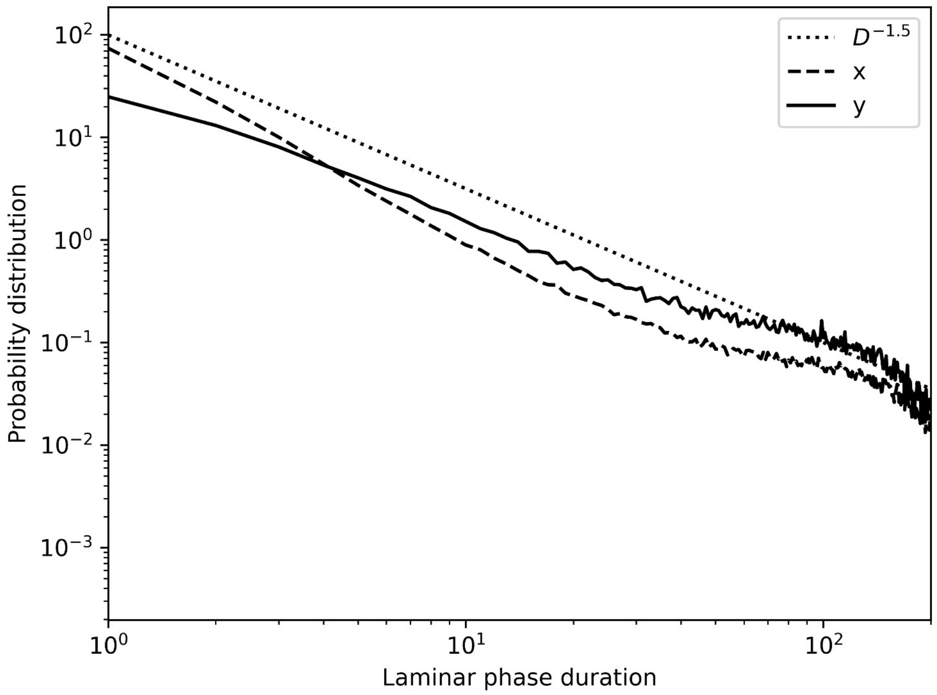




Stochastic carrying capacity

$0 \leq \rho \leq 2.1$





Beddington’s model

Host

$$N_{t+1} = \delta N_t \exp\left[r\left(1 - \frac{N_t}{K}\right) - a P_t \right]$$

Parasitoid

$$P_{t+1} = b N_t \left[1 - \exp\left(-a P_t\right)\right]$$

Vissio Gabriele, Provenzale Antonello (2022): *On-off intermittency and irruptions in host-parasitoid dynamics,* Journal of Theoretical Biology 546, 111174

Beddington's model

Host

$$N_{t+1} = \delta N_t \exp\left[r\left(1 - \frac{N_t}{K}\right) - a P_t \right]$$

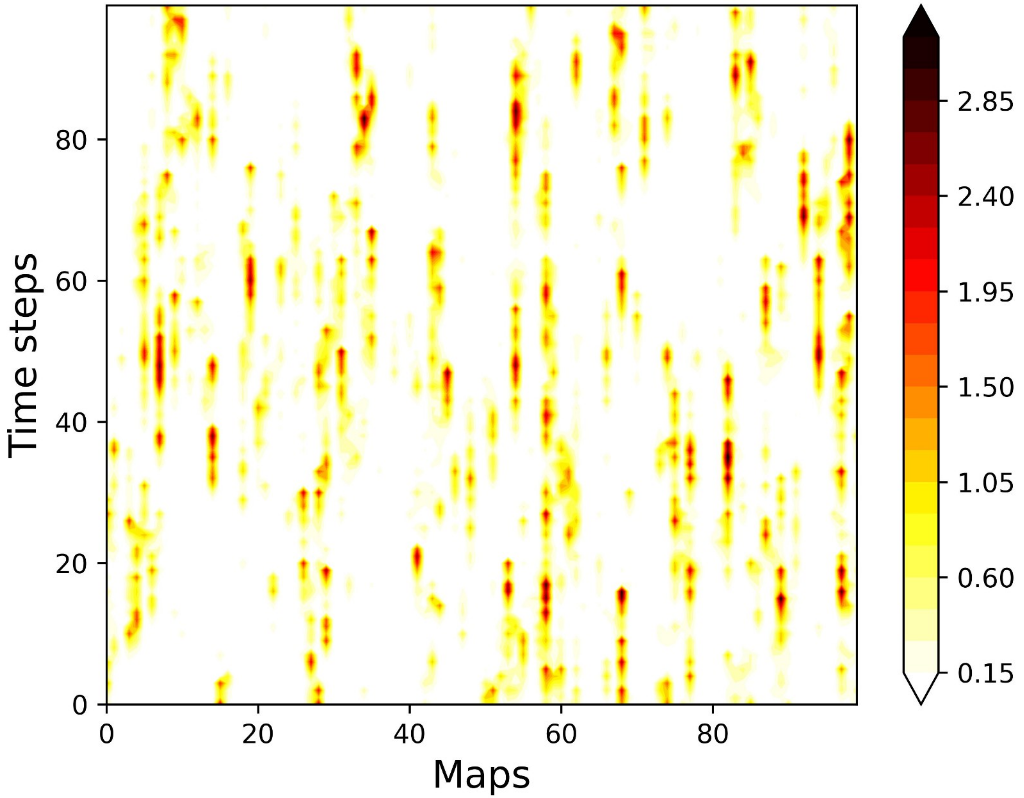
Parasitoid

$$P_{t+1} = b N_t \left[1 - \exp\left(-a P_t\right)\right]$$

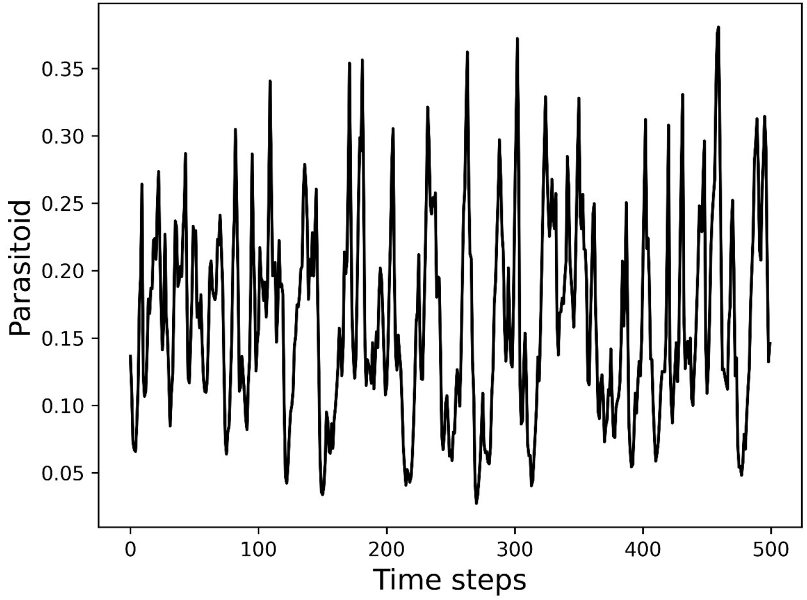
Local coupling

$$N_{t+1}^{k} = (1-\gamma) f_N\left(N_t^k ; a_t^k\right) + \frac{\gamma}{2}\left[f_N\left(N_t^{k-1} ; a_t^{k-1}\right) + f_N\left(N_t^{k+1} ; a_t^{k+1}\right)\right]$$

Beddington’s model



$$0 \leq \delta \leq 0.15, \gamma = 0.001$$



Beddington's model

Host

$$N_{t+1} = \delta N_t \exp\left[r \left(1 - \frac{N_t}{K} \right) - a P_t \right]$$

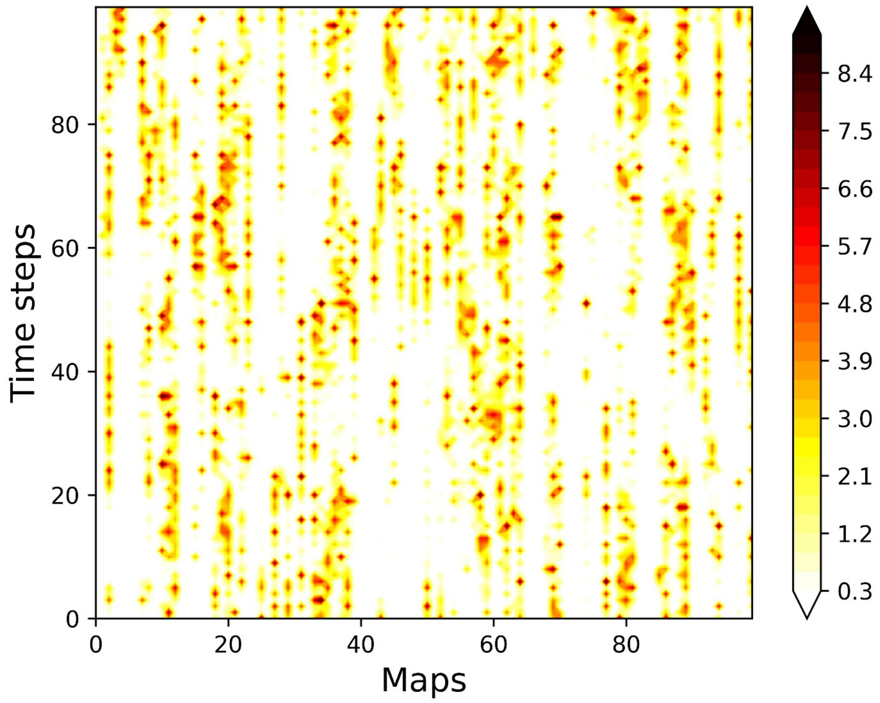
Parasitoid

$$P_{t+1} = b N_t \left[1 - \exp\left(- a P_t \right) \right]$$

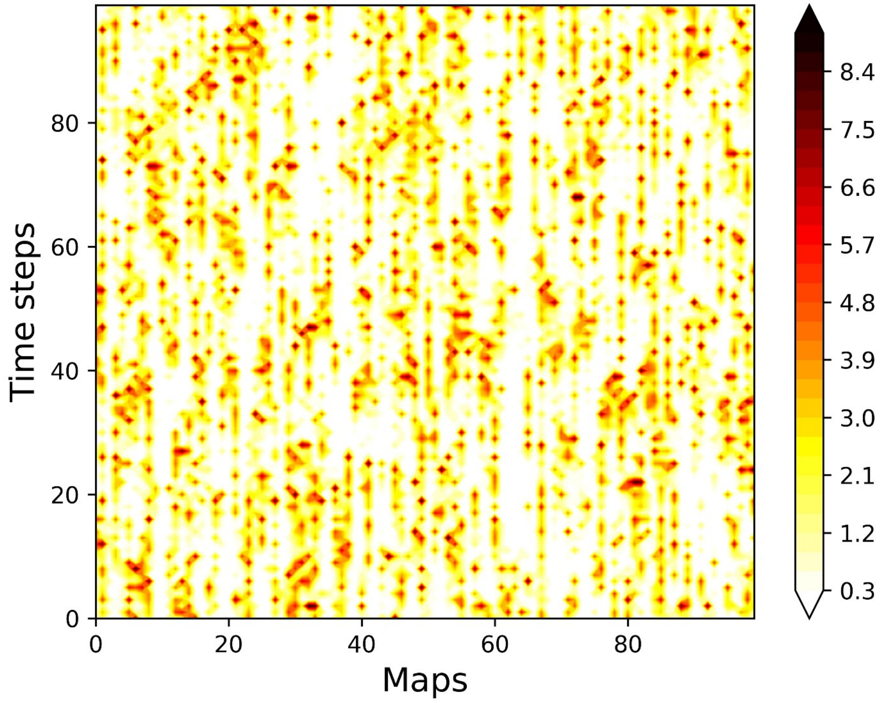
- Local coupling deletes on-off intermittency
- Local coupling produces on-off intermittency

Beddington's model

$0 \leq a \leq 0.6, \gamma = 0$

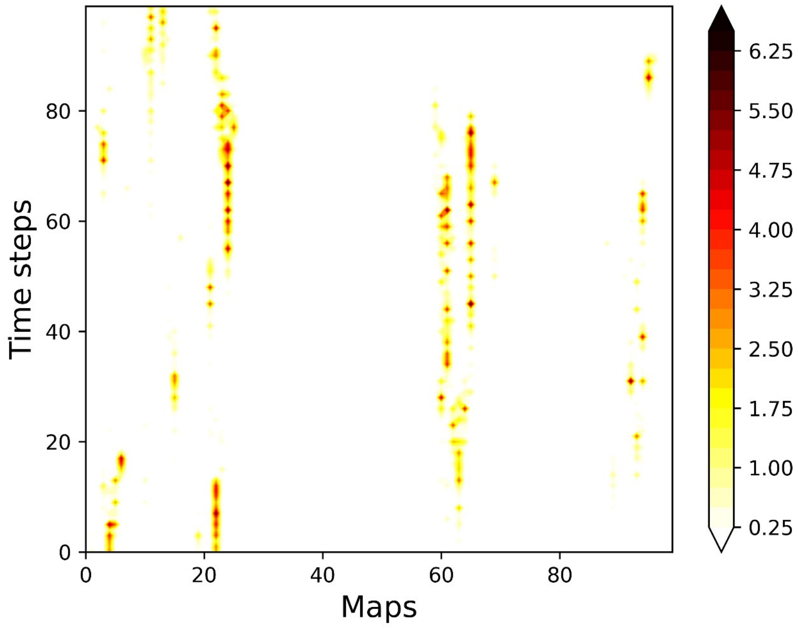


$0 \leq a \leq 0.6, \gamma = 0.0001$

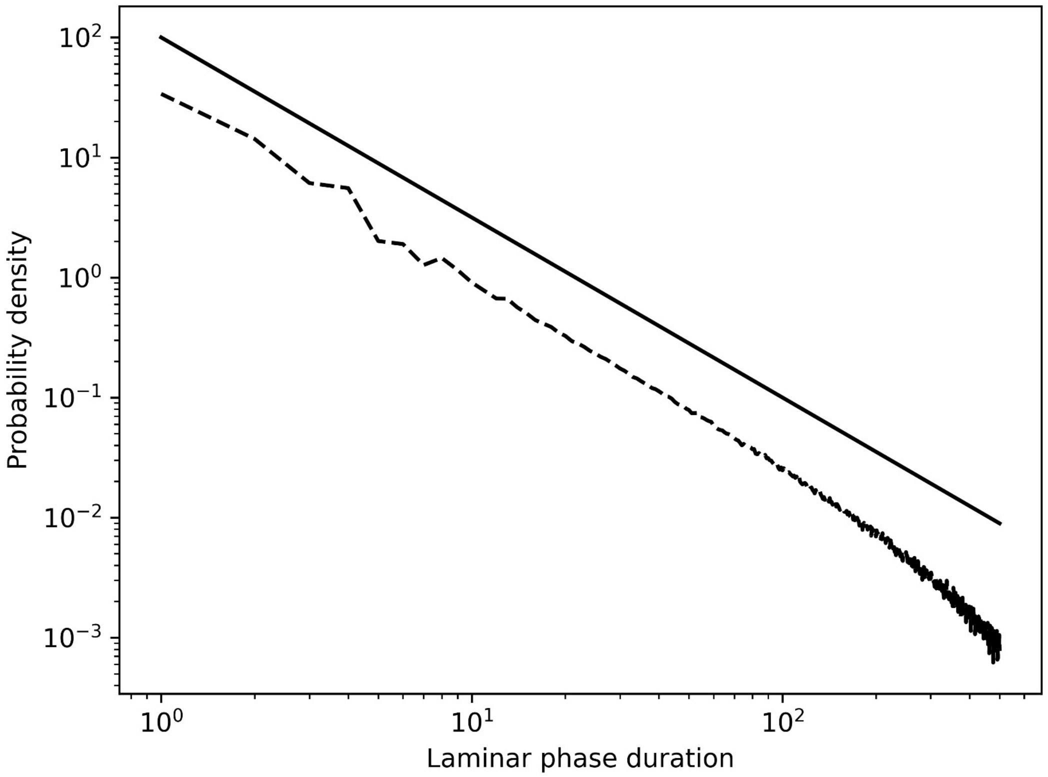


Beddington’s model

$$0 \leq a \leq 0.4, \gamma = 0.005$$



$$PDF \sim D^{-1.5}$$



Recap

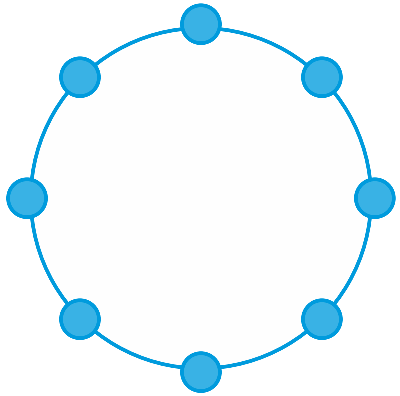
- Environmental forcing can induce on-off intermittency in the system, qualitatively explaining outbreaks in population size
- Intermittency in population not directly involved by the forcing
- Spatial coupling induces or suppresses on-off intermittency

Forcing with a conceptual model

$$\frac{dp}{dt} = \alpha r p \left(1 - \frac{p}{k}\right) - \frac{p^2}{1+p^2}$$

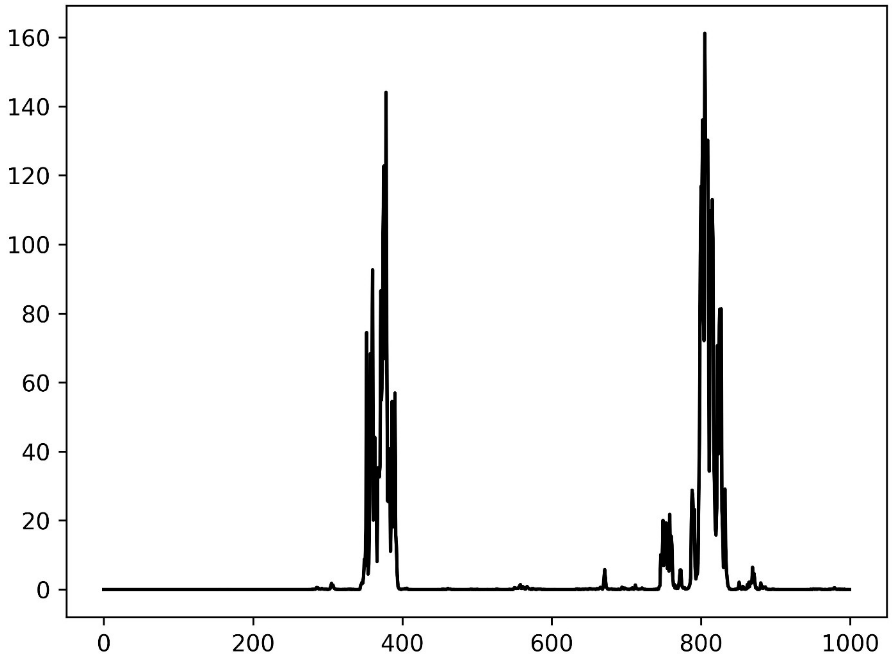
$$\frac{dX_k}{dt} = X_{k-1}\left(X_{k+1} - X_{k-2}\right) - \alpha \theta_k - \gamma X_k + F$$

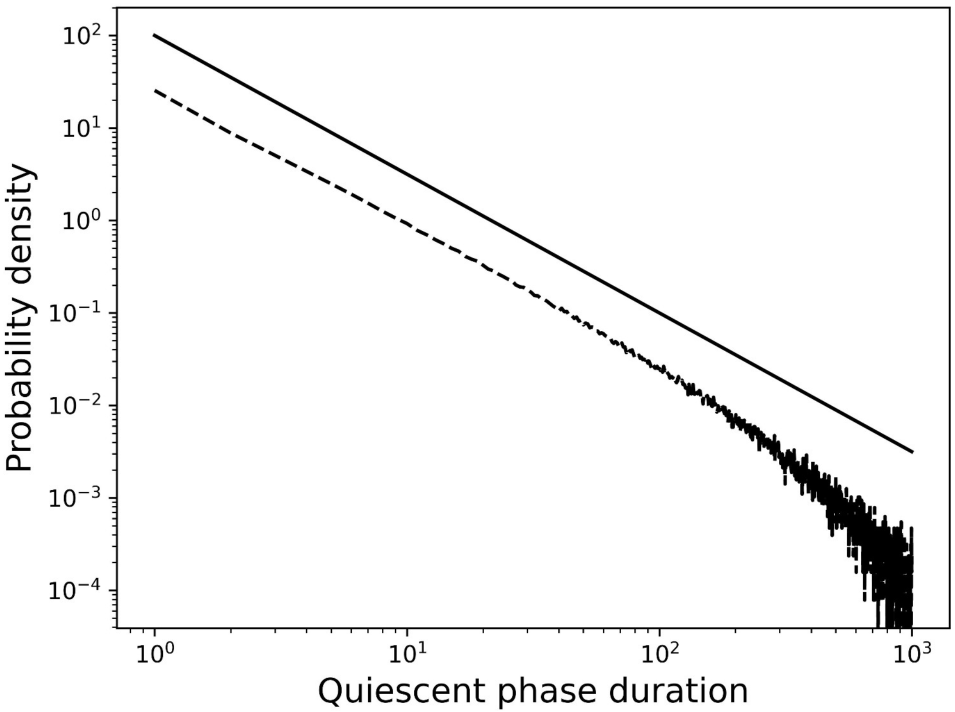
$$\frac{d\theta_k}{dt} = X_{k+1}\theta_{k+2} - X_{k-1}\theta_{k-2} + \alpha X_k - \gamma \theta_k + G$$



Vissio Gabriele, Lucarini Valerio (2020), Mechanics and thermodynamics of a new minimal model of the atmosphere, European Physical Journal Plus 135: 807

Forcing with a conceptual model





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