Noise, demographic sampling and population dynamics: implications of climate change

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Uncertainty

Bayes Theorem

$P(A|B)P(B)=P(AB)$

$P(B|A)P(A)=P(AB)$

$\mathbf{P(A|B)\ \alpha\ P(B|A)P(A)}$

Post is **Prior** x **Likelihood**

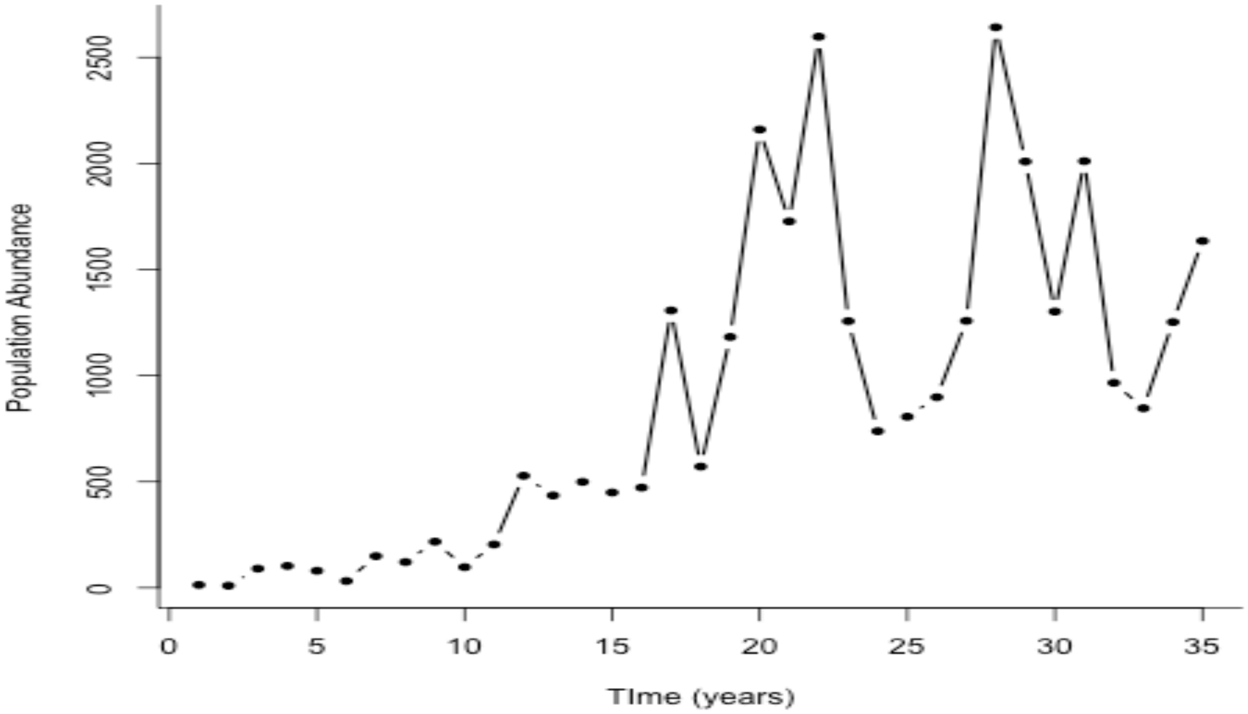
$\mathbf{P(A|B)\ \alpha\ P(A)\ P(B|A)}$

Plan

- Endangered butterflies
  - Noise, regional and local dynamics
- Metapopulation microcosms
  - Demographic sampling and alternative states
- Silver-Y Moth
  - Migration and dispersal dynamics
- Plants in the Holocene
  - Climate change and ecological dynamics

High Brown Fritillary Metapopulation Dynamics

High Brown Fritillary Dynamics



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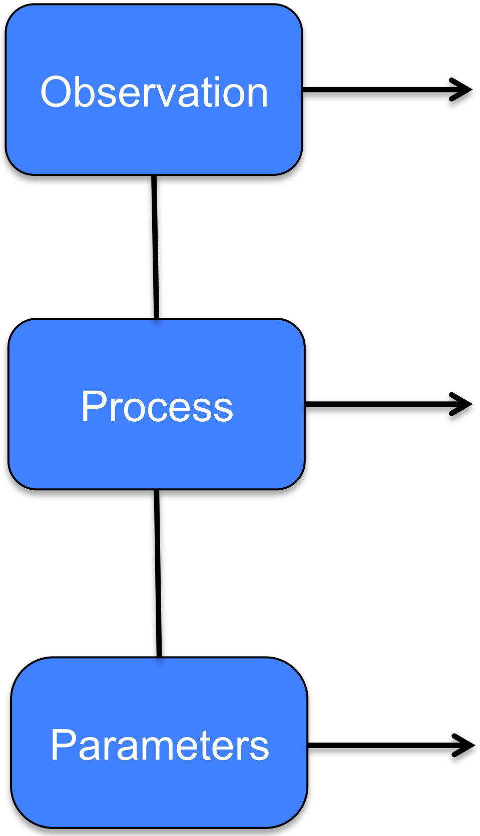
Allee Effects Model….



Counts of Species

Observation → **Poisson** (Measurement Error)

$$\frac{dN}{dt} = rN\left(1-\frac{N}{K}\right)\left(1-\frac{A+C}{N+C}\right)+\lambda$$

Process → **Normal** (Process Error)

Parameters → Parameter Error

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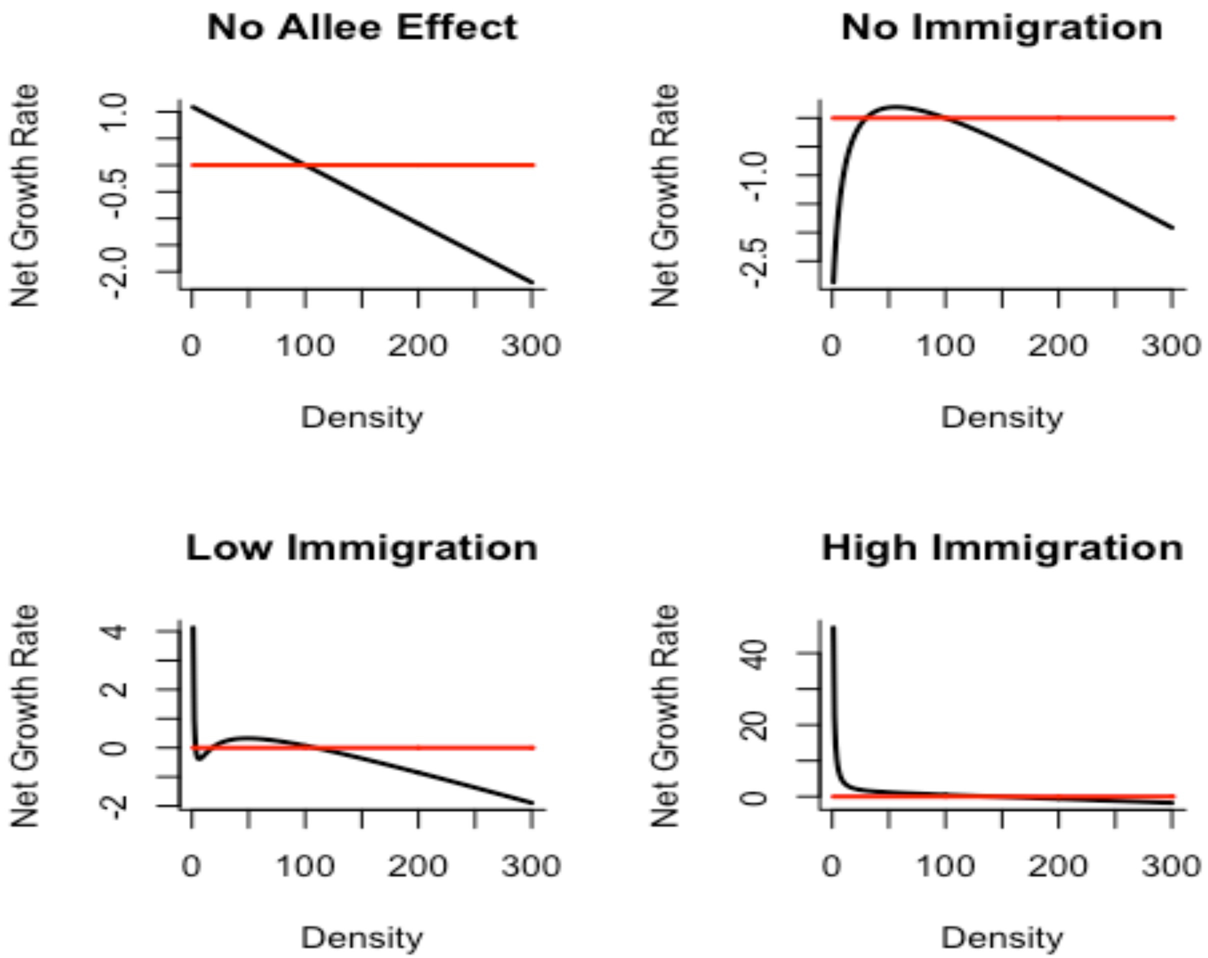
… has ecological dynamical flexibility

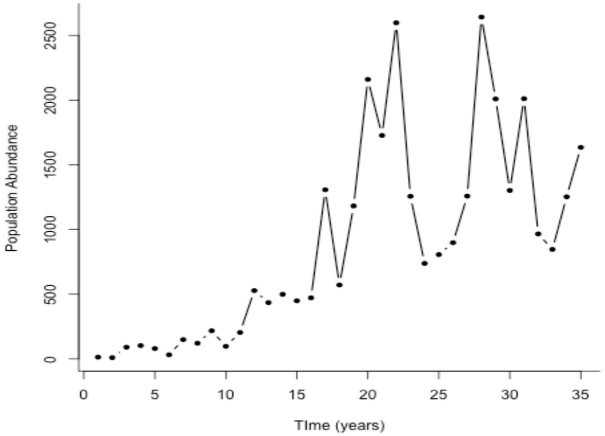


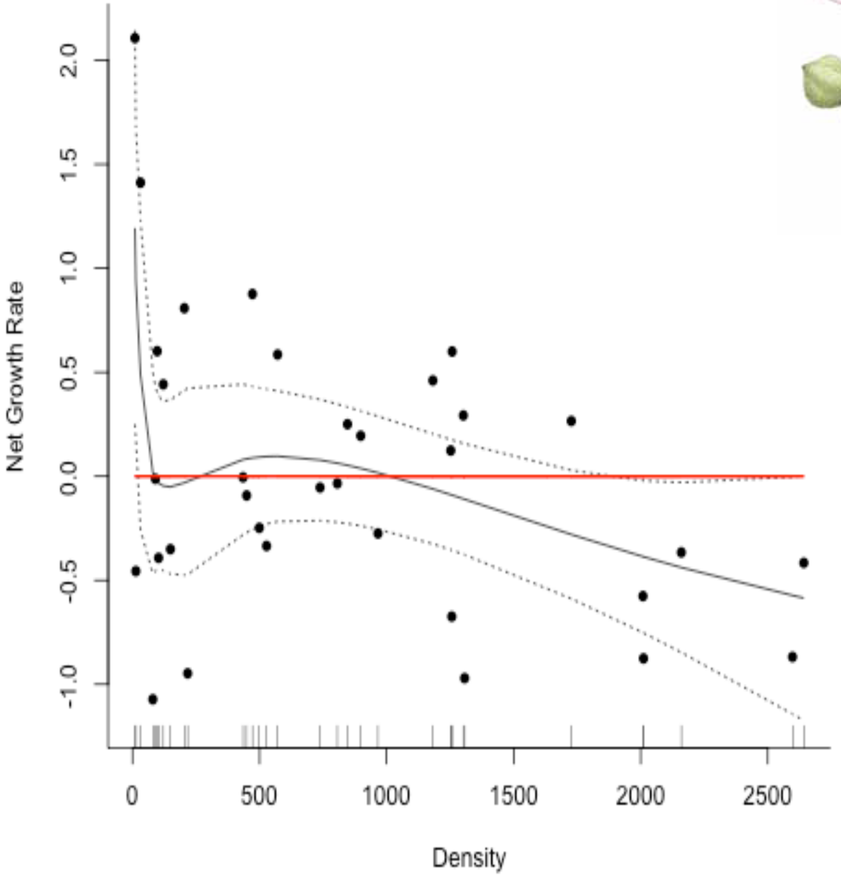
Resilience

Resilience: How robust is a population to a perturbation?

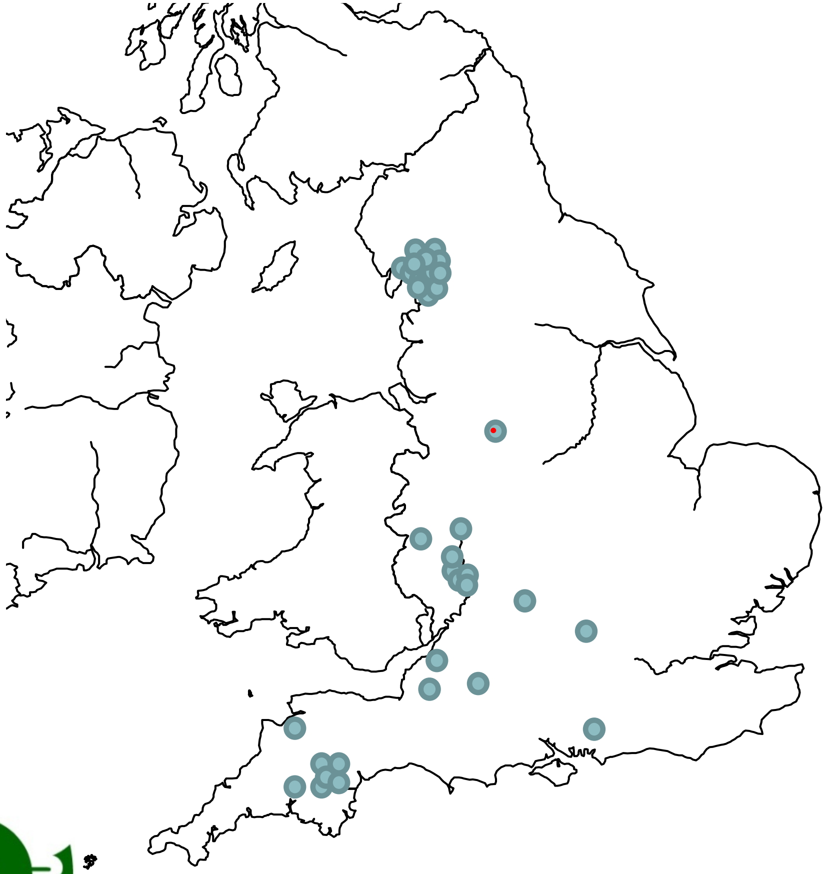
Alternatively, in the case of the High Brown Fritillary, we might define resilience as ‘how close is the regional (or a local) population to an Allee threshold’?

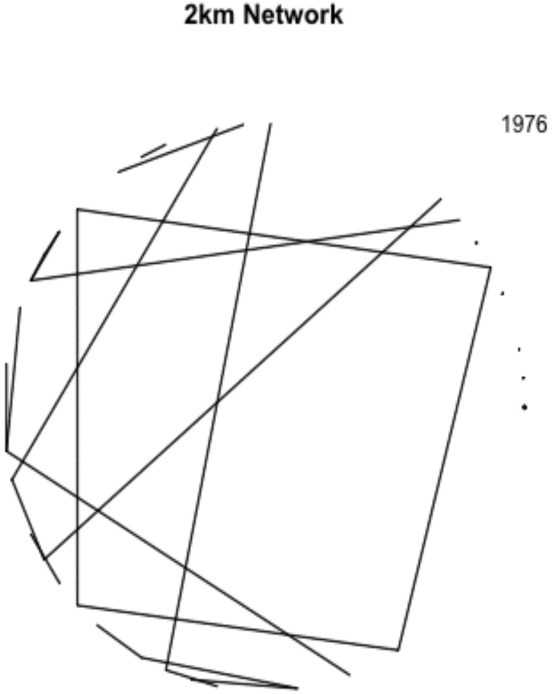
High Brown Fritillary Dynamics





High Brown Fritillary Distribution





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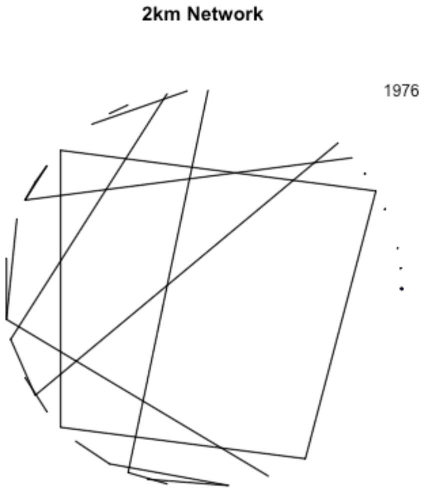
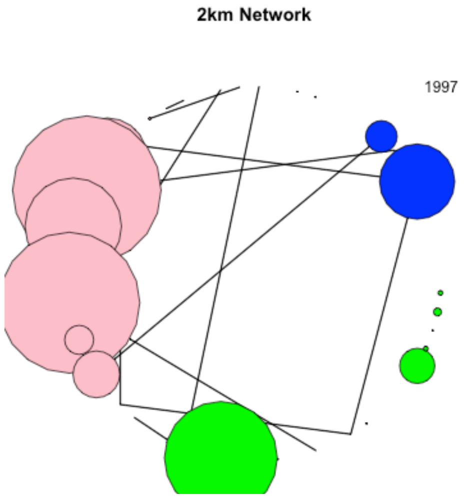
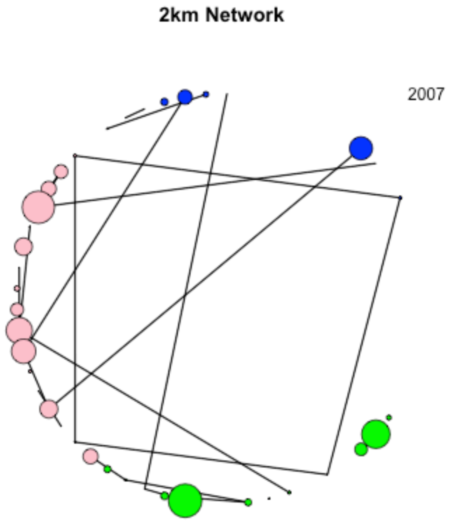
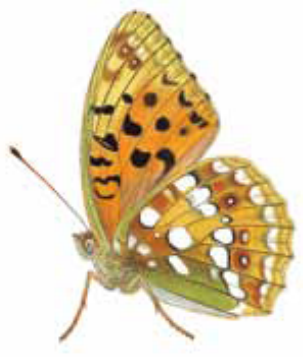
High Brown Fritillary Distribution


2km Network


2km Network


2km Network



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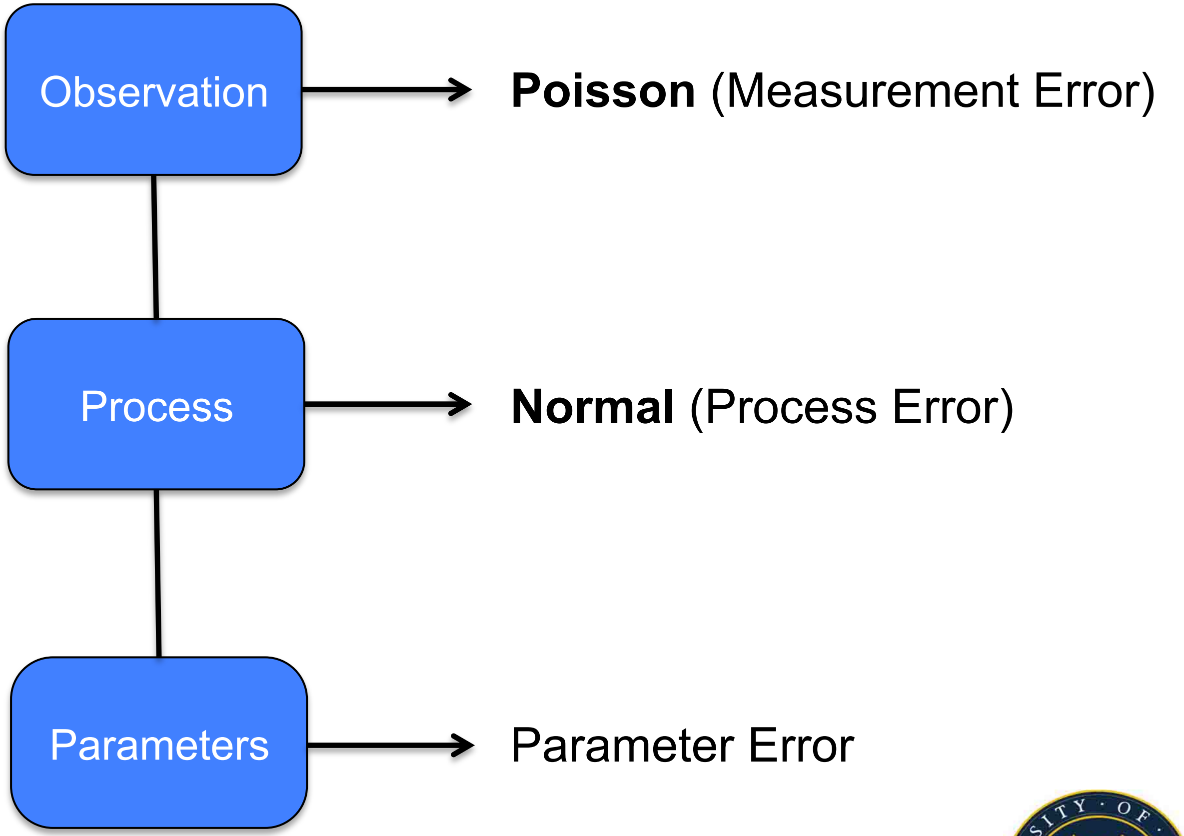
Allee Effects Model



Counts of Species

$$\frac{dN}{dt} = rN\left(1-\frac{N}{K}\right)\left(1-\frac{A+C}{N+C}\right)+\lambda$$

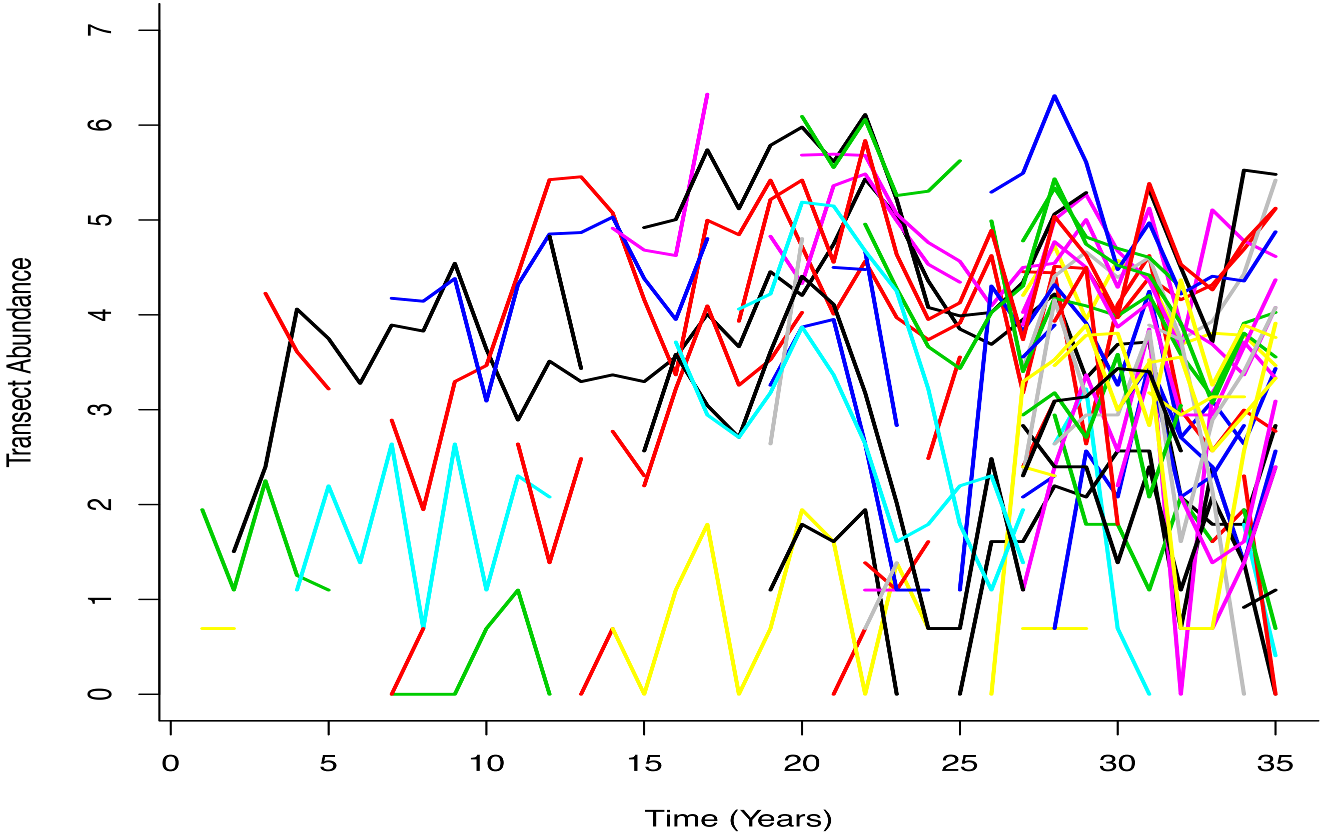
Poisson (Measurement Error)

Normal (Process Error)

Parameter Error

Heterogeneous local dynamics

$$p(\mathbf{H} \mid D_{i,1},.......,D_{i,t}) \propto \prod_{t=1}^{T} \left[D_{i,t} \middle| n_{i,t}\right]\left[n_{i,t} \middle| X_{i,t}, \sigma_e^2\right]\left[X_{i,t} \middle| X_{i,t-\delta t}, \sigma_d^2\right]\left[\Phi_i\right]$$



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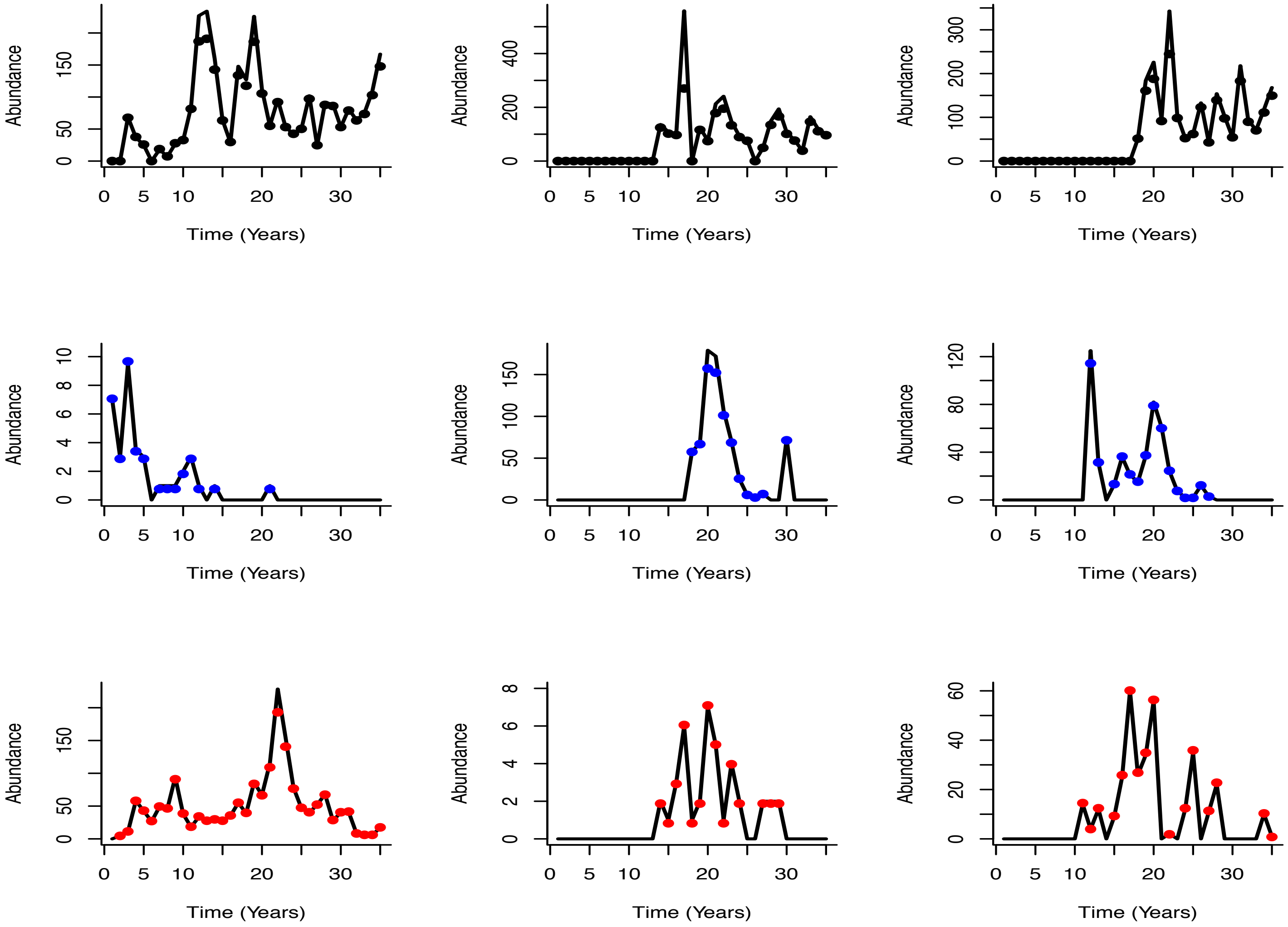
Predicted dynamics from hierarchical Bayes approach



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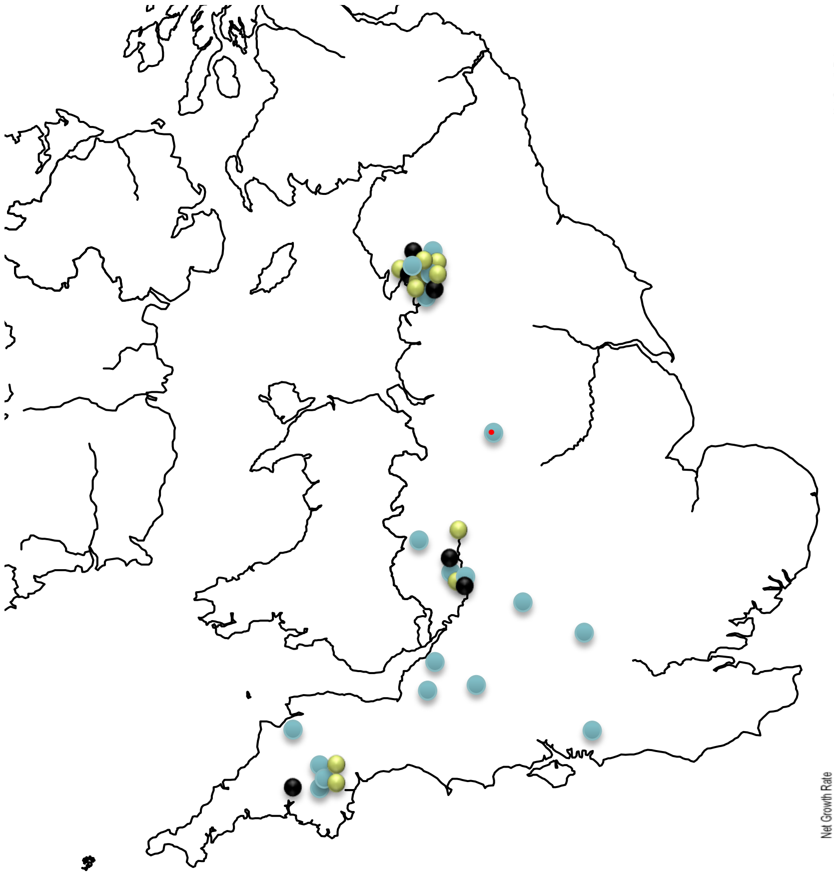
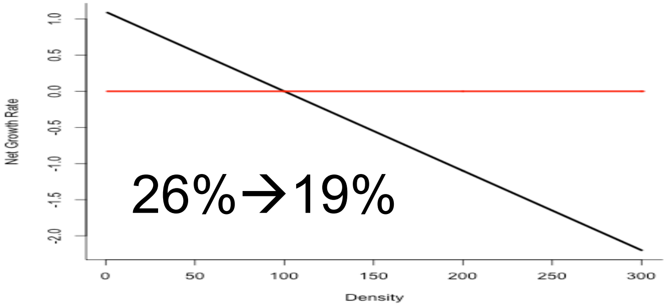
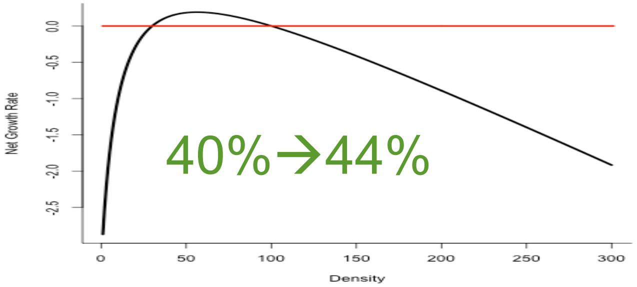
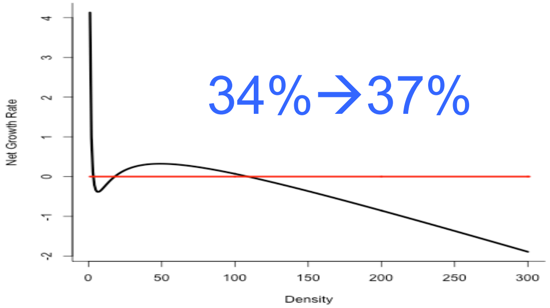
High Brown Fritillary in Space









Bruchid Metapopulation Dynamics

Local and Regional Heterogeneity

Linking populations together through limited dispersal is known to promote persistence in bruchid-parasitoid metapopulation assemblages:

- Through rescue effects in single bruchid – parasitoid interactions (Bonsall et al. 2002; Bonsall & Hastings 2004)

- Allow inferior bruchid competitors to escape effects of interspecific or apparent competition (Bonsall et al. 2005; Bull et al. 2007; Hunt & Bonsall 2009)

- Dispersal in heterogeneous environments can lead to source-sink dynamics (Strevens & Bonsall 2011)

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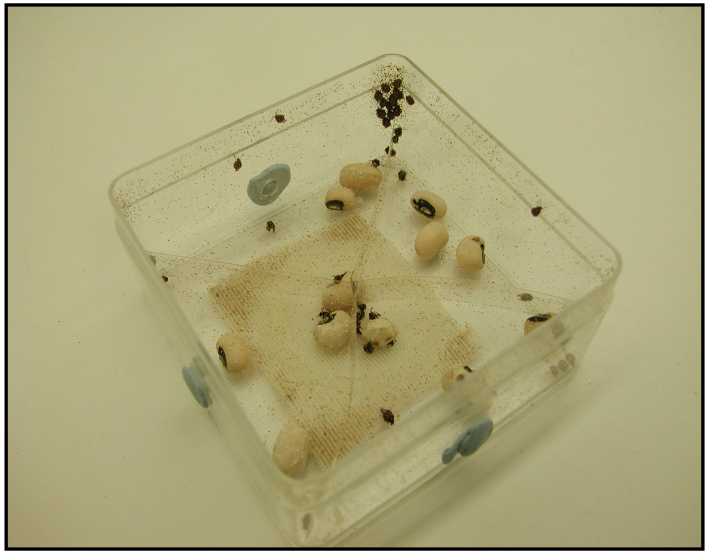
The beasts

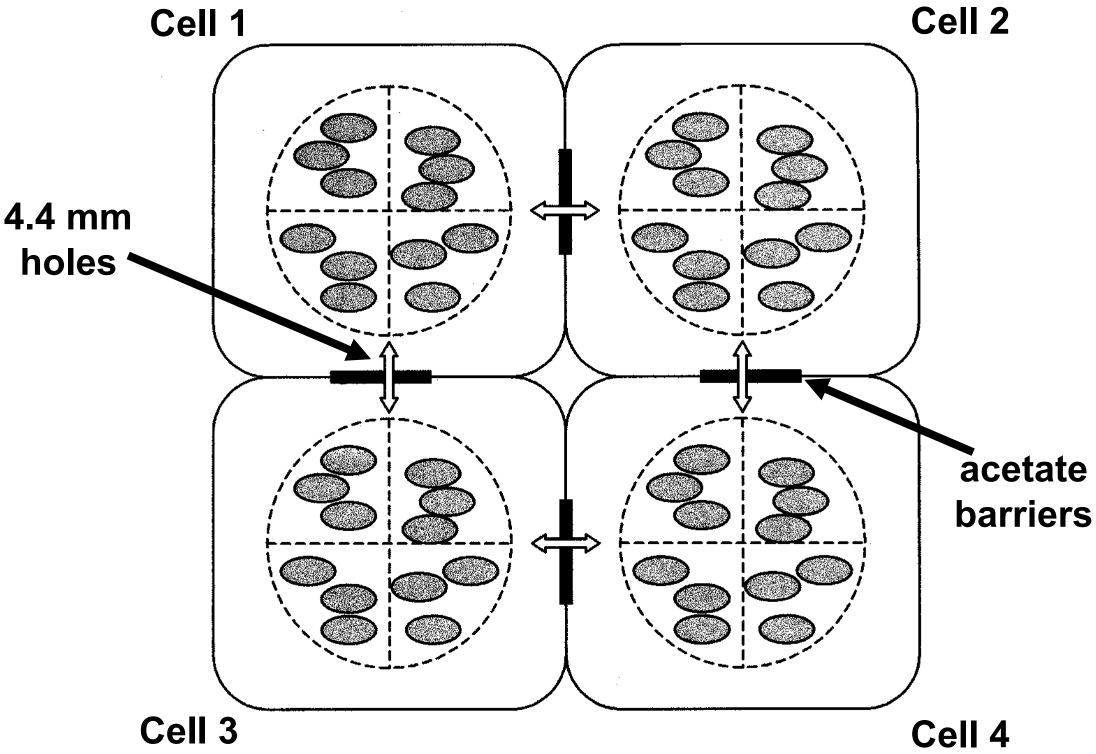
Anisopteromalus calandrae

Callosobruchus chinensis

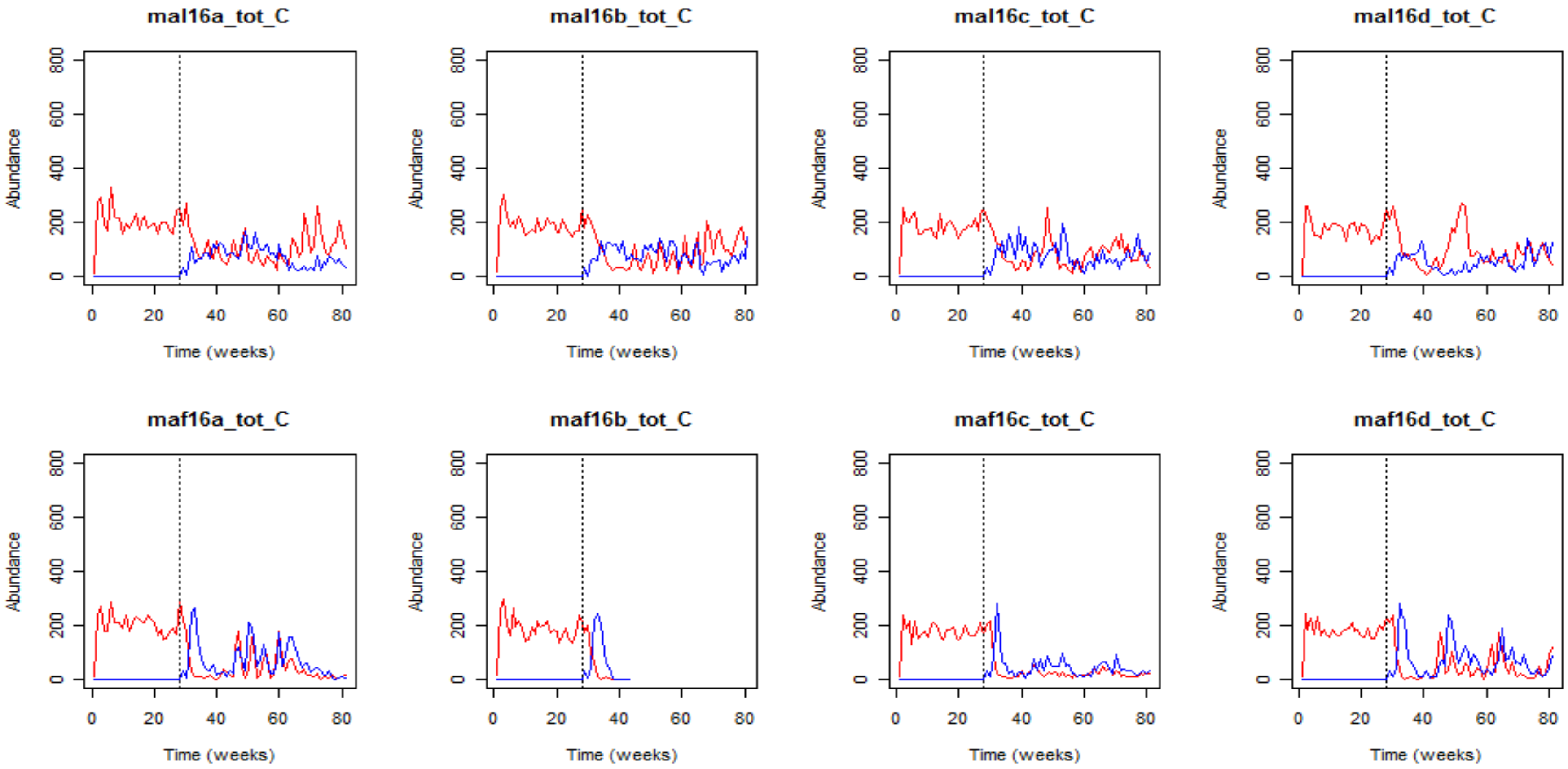
Callosobruchus maculatus

Metapopulation microcosms are magnificent….





Limited dispersal drives regional persistence…



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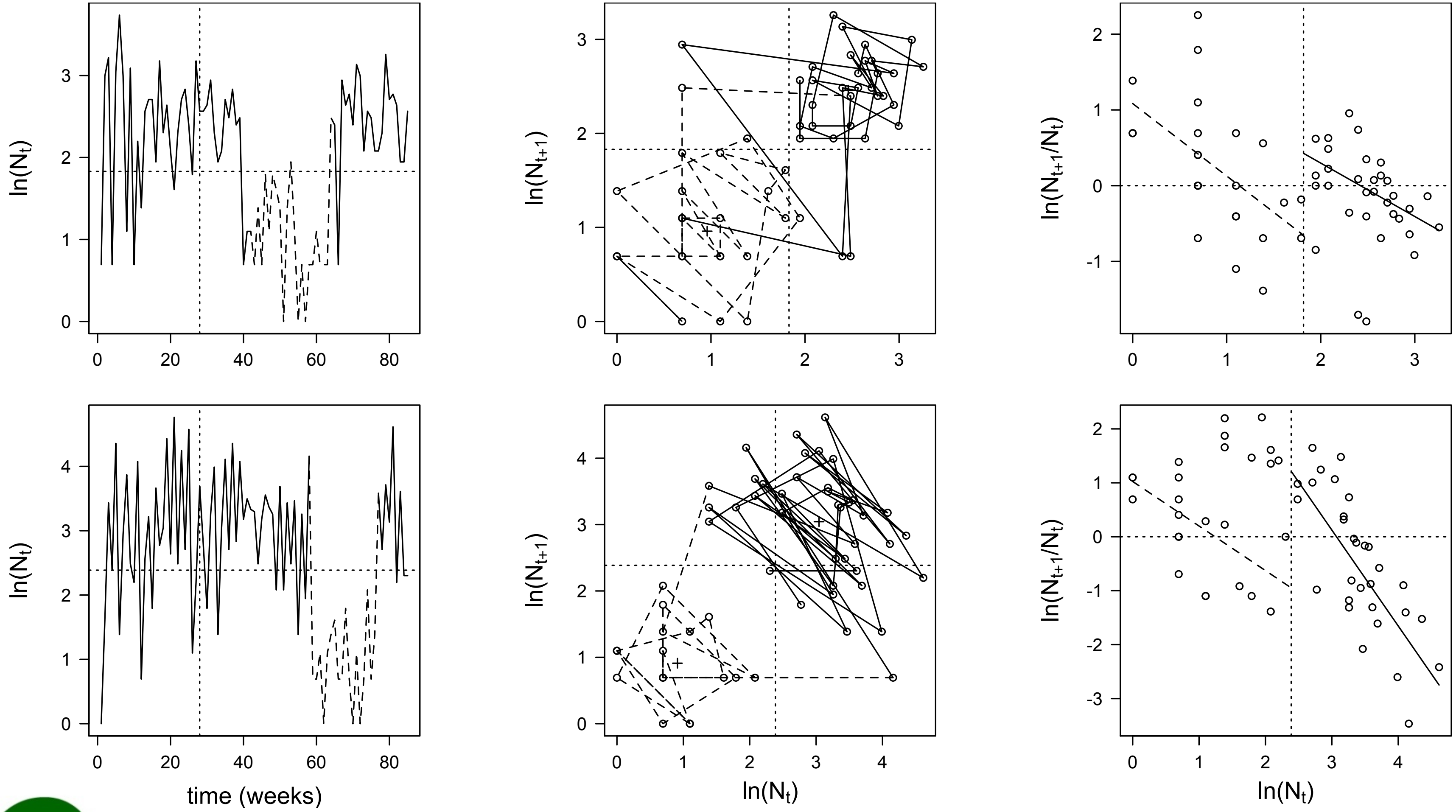
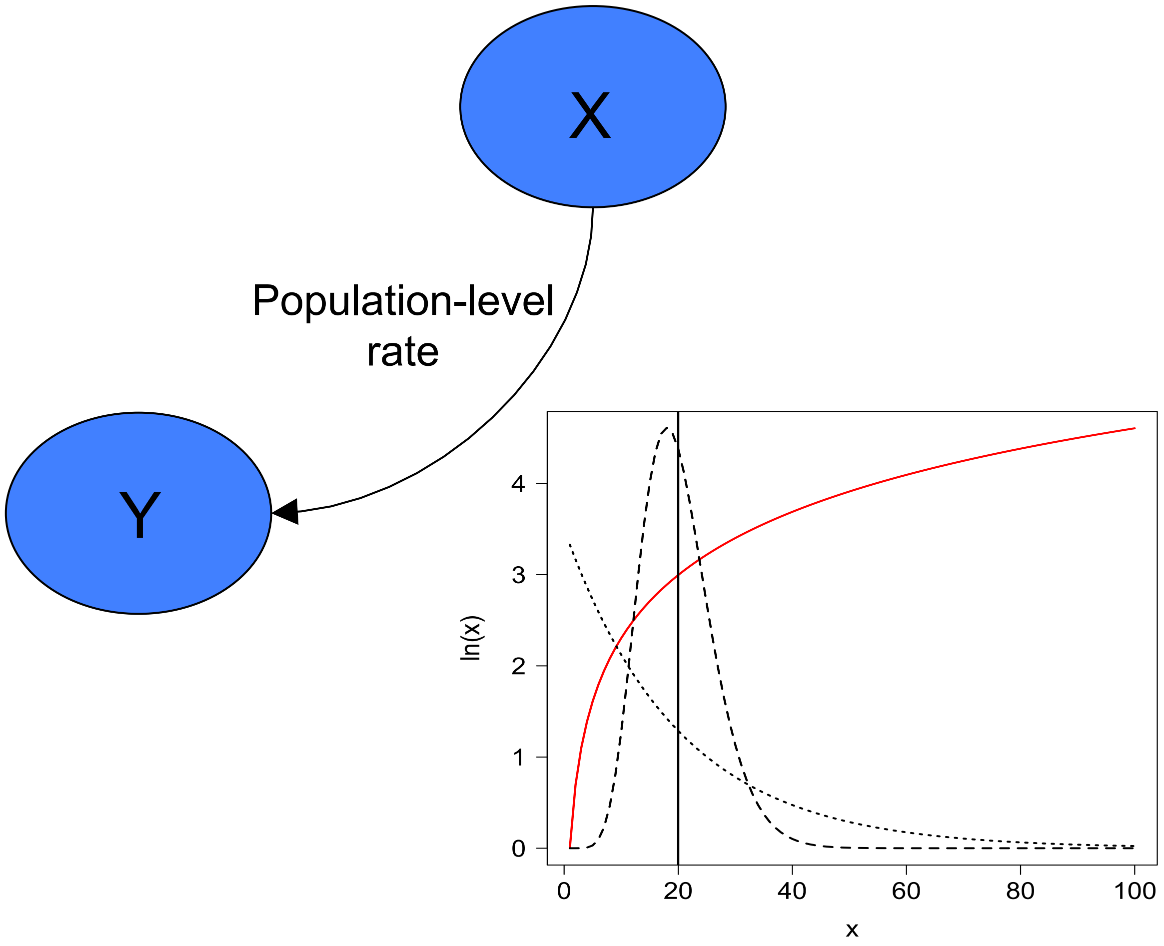
Heterogeneous local dynamics….



…driven by demographic sampling



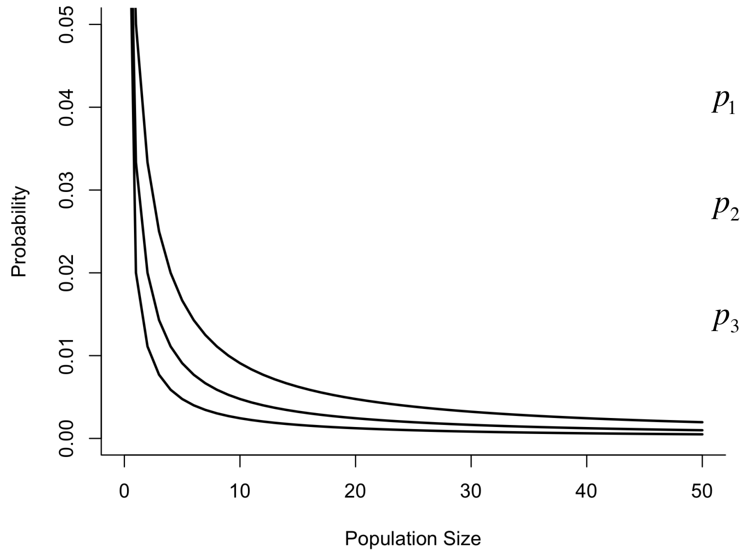
Population-level rate

Demographic sampling drives dynamics…

Stochastic Birth-Death-Dispersal process

$$\frac{dp_x(t)}{dt} = p_{x-1}r(x-1) + p_{x+1}\big(\mu(x+1)+\lambda\big) - (r(x)+\mu(x)+\lambda)p_x$$

$$\frac{dp_0(t)}{dt} = p_1(\mu+\lambda) - \lambda p_0$$

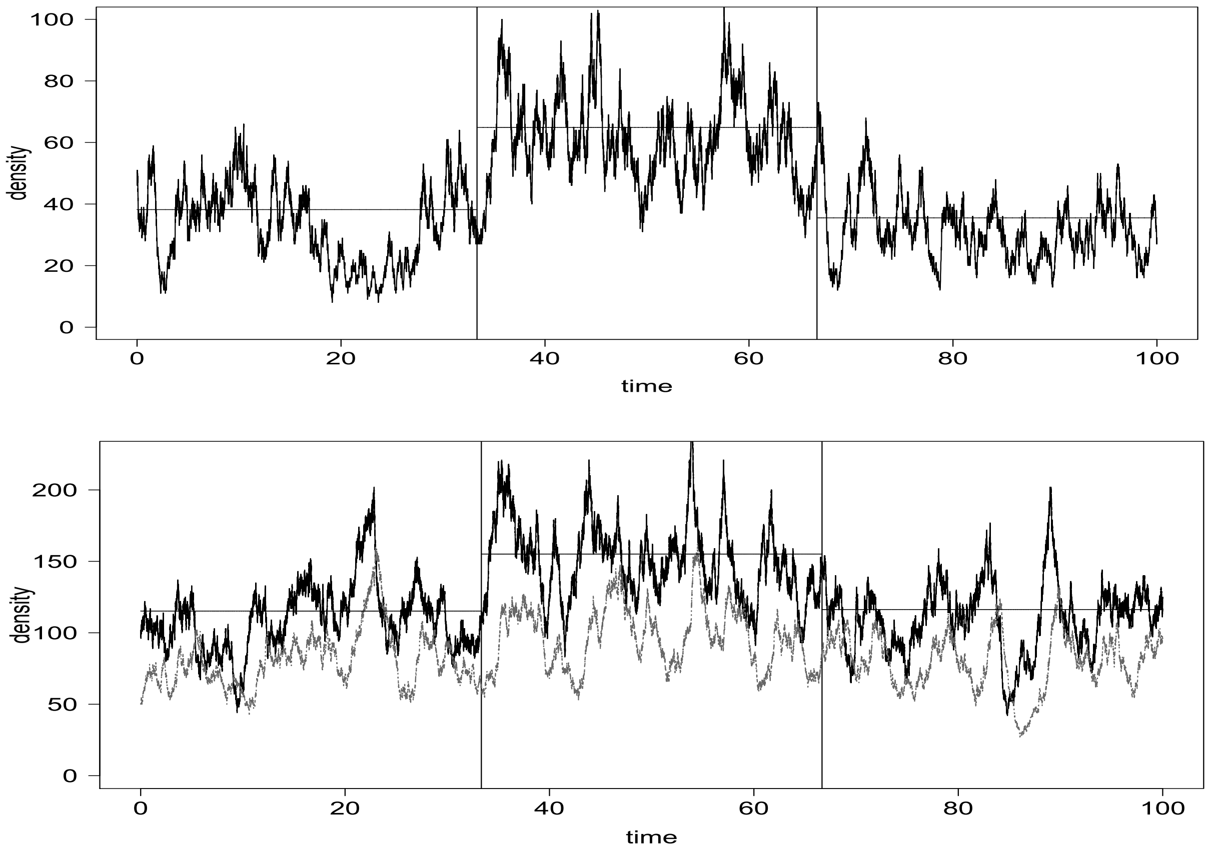


$$p_1 = \frac{\lambda p_0}{\mu+\lambda}$$

$$p_2 = \frac{(r+\mu+\lambda)\lambda p_0}{(\mu+\lambda)(2\mu+\lambda)}$$

$$p_3 = \frac{(2r+2\mu+\lambda)(r+\mu+\lambda)\lambda p_0}{(\mu+\lambda)(2\mu+\lambda)(3\mu+\lambda)} - \frac{r\lambda p_0}{(\mu+\lambda)(3\mu+\lambda)}$$

Demographic sampling drives dynamics...

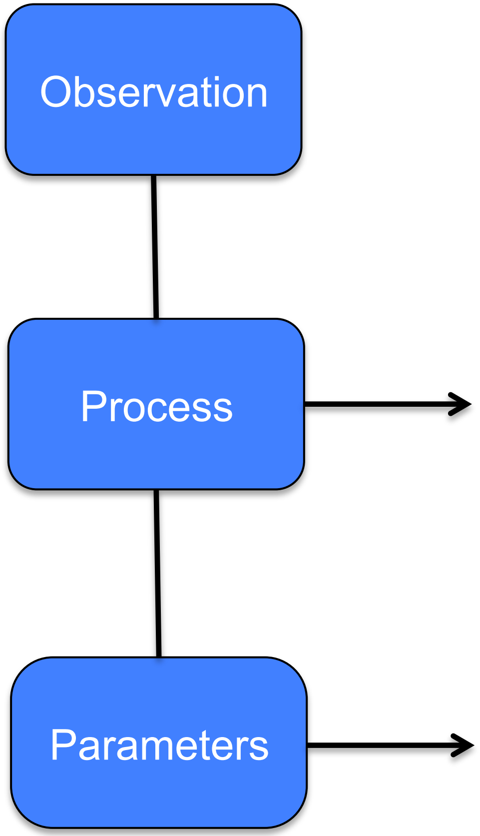


Predator-prey model

Counts of bruchids
and wasps

$$\frac{dB(t)}{dt} = rB\left(1 - \frac{B}{K}\right) - \alpha BP$$

$$\frac{dP(t)}{dt} = c\alpha BP - uP$$



Observation

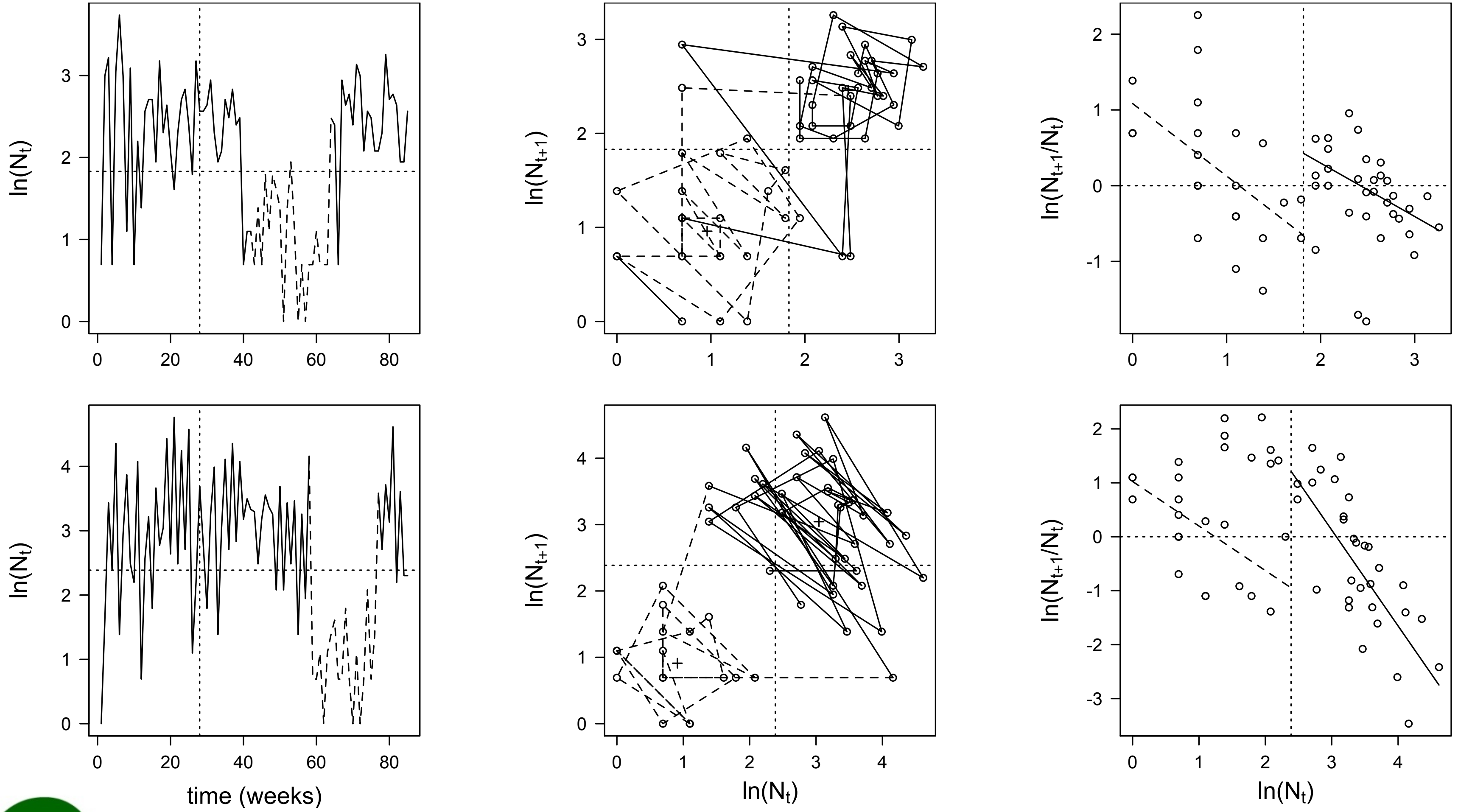
Process

Parameters

Normal (Process Error)

Parameter Error

Observed and predicted local dynamics



Silver-Y (*Autographa gamma*) dynamics

Chapman J. *et al.* (2012) *Proc. Natl. Acad. Sci.*
109: 14924-14929.

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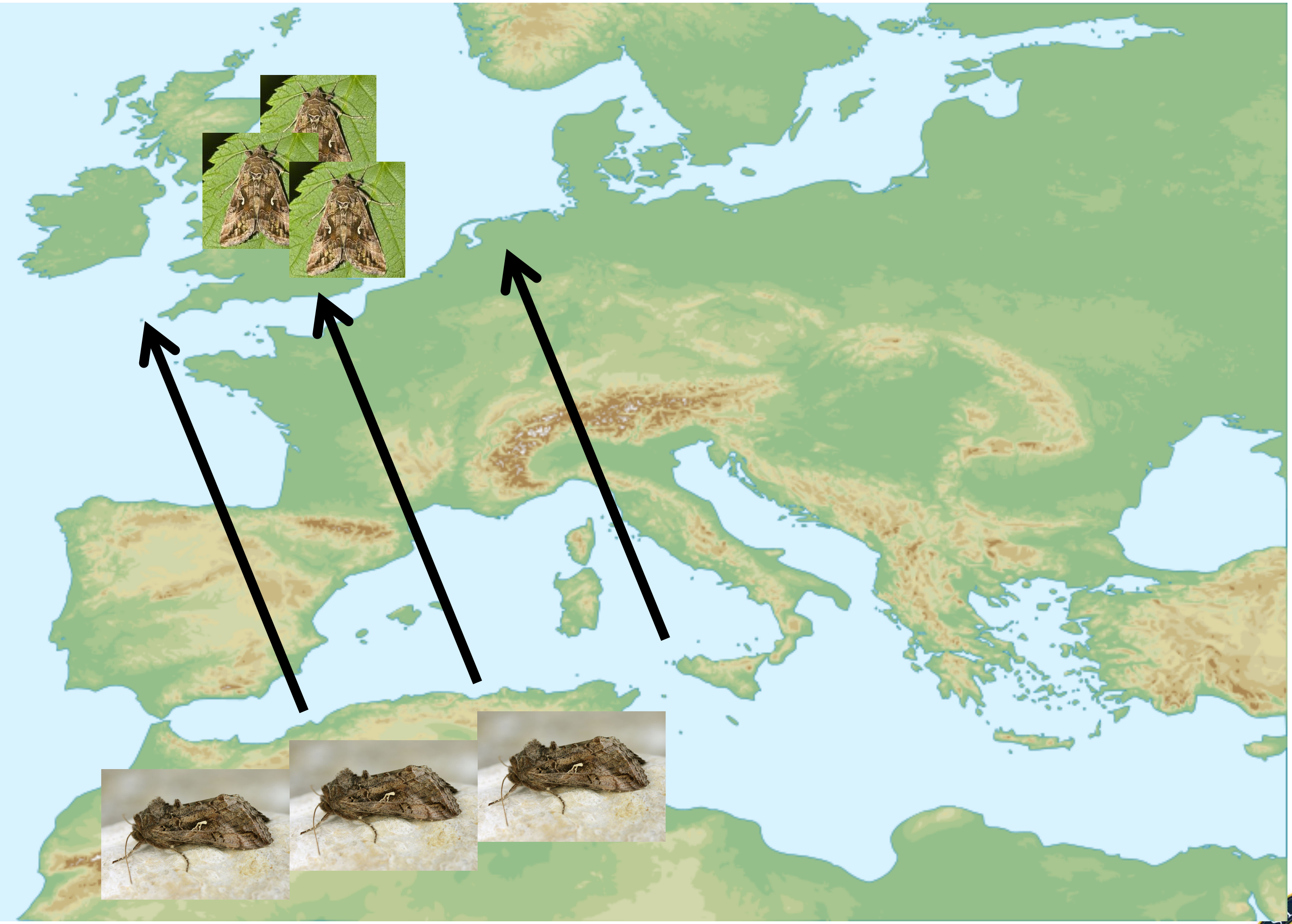
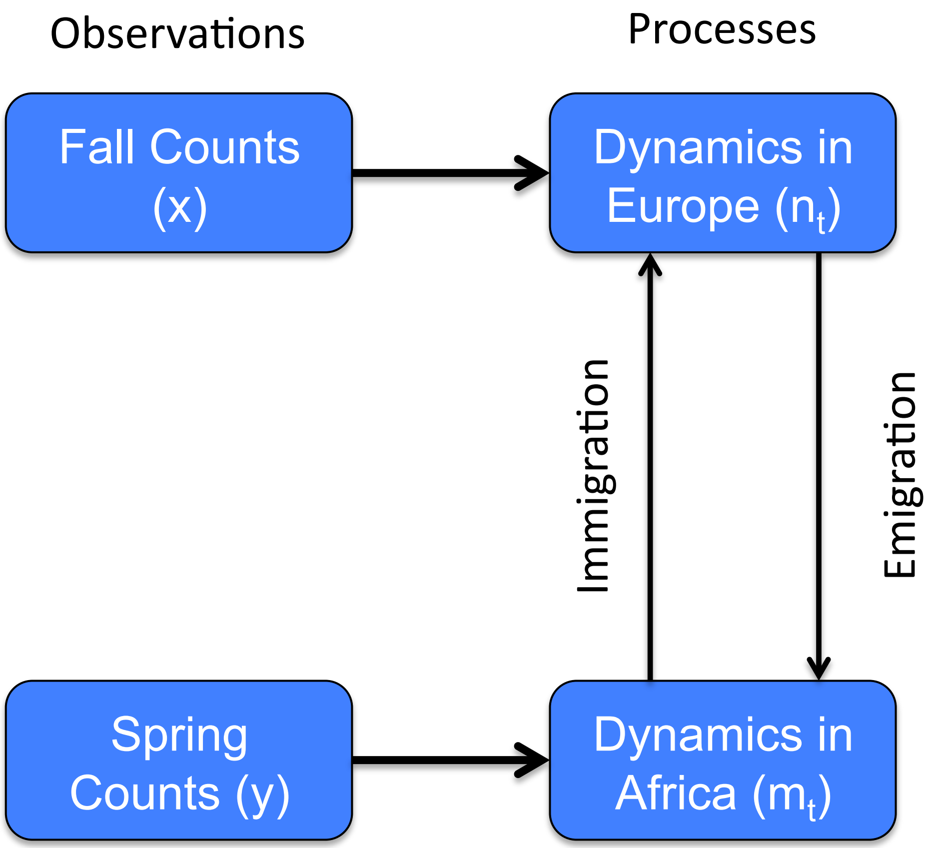
Pied-Piper Silver-Y Dynamics



Silver-Y Dynamics



Observations

Processes

Fall Counts (x)

Dynamics in Europe (n_t)

Immigration

Emigration

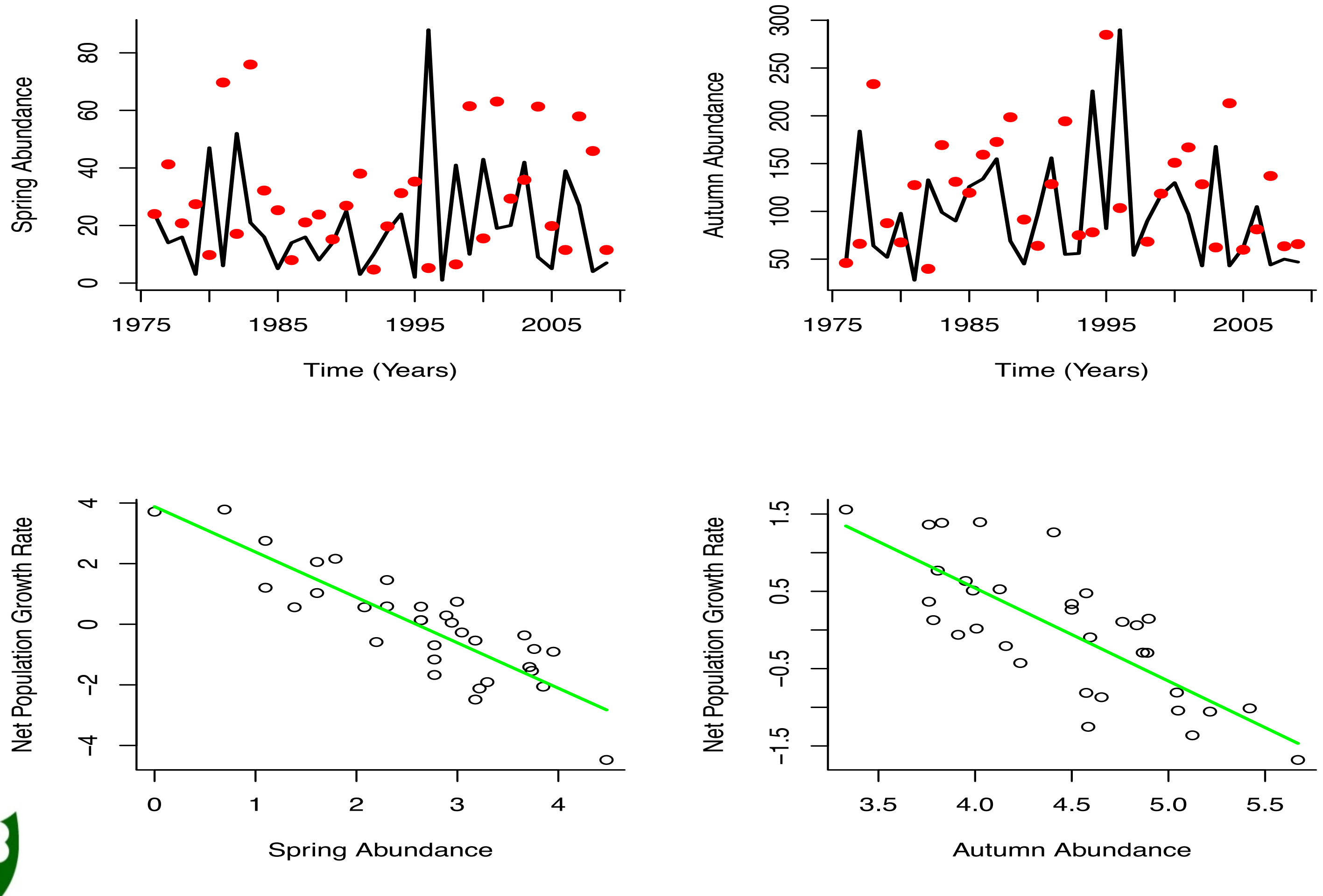
Spring Counts (y)

Dynamics in Africa (m_t)

$$n_t = d(m_{t-1}) + \lambda_n n_{t-1} f(n_{t-1})$$

$$m_t = d(n_{t-1}) + \lambda_n m_{t-1} f(m_{t-1})$$

Autographa Population Dynamics



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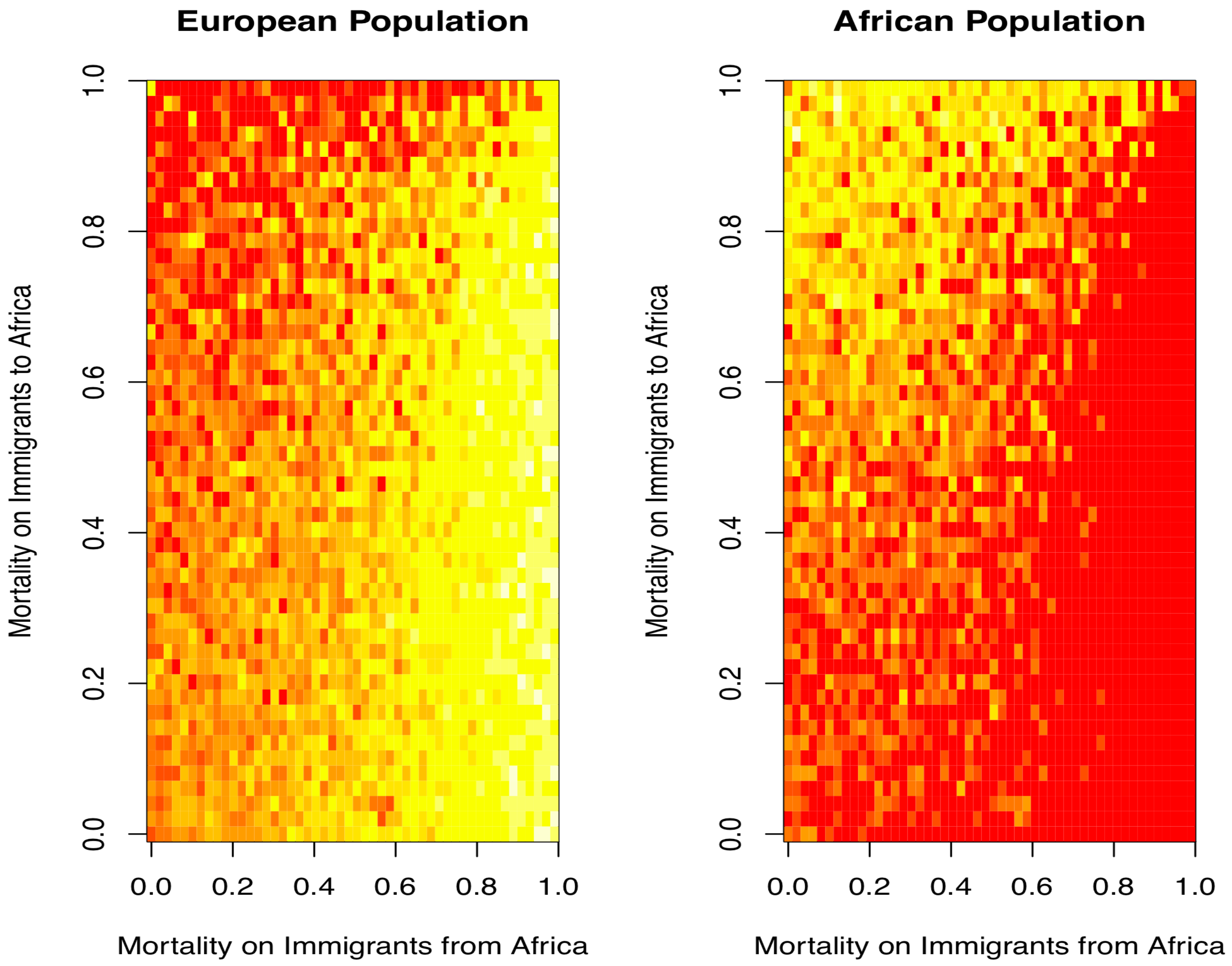
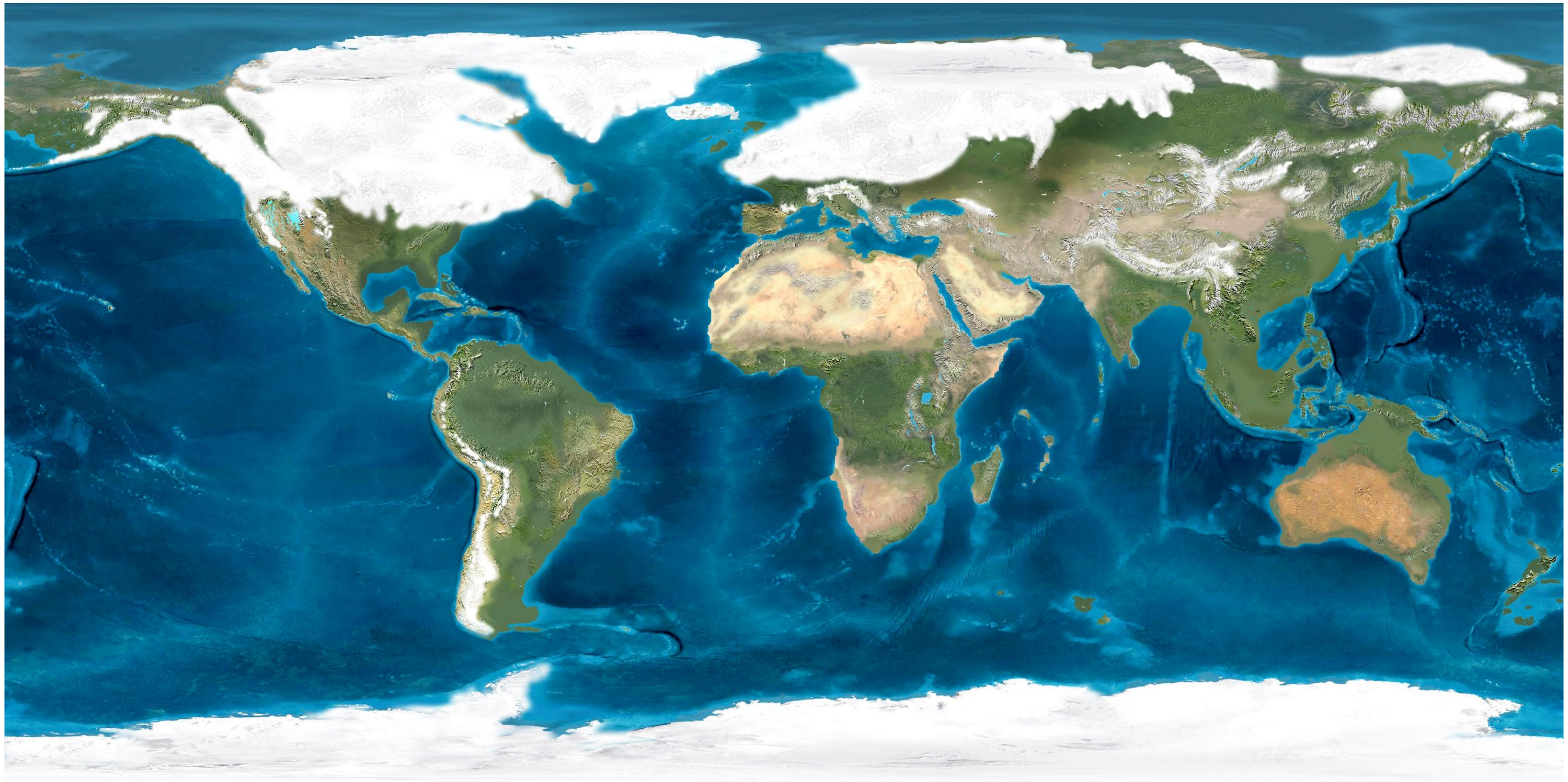
Dispersal mortality and *Autographa* dynamics

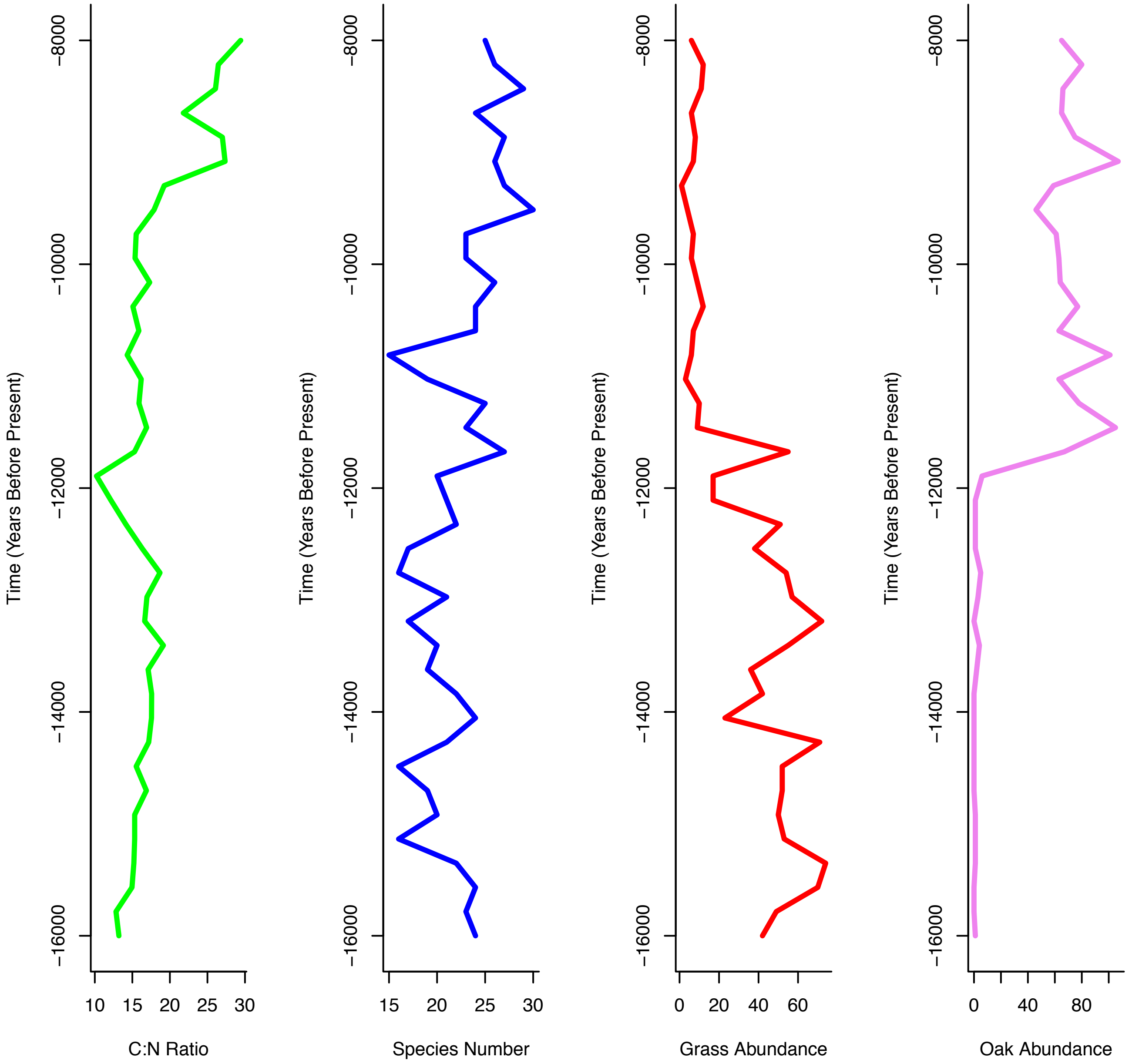


Paleo-ecological dynamics

Jeffers, E.A. et al. 2010 (PLoS ONE, 6(1), e16134), 2011 (Journal of Ecology, 99, 1063-1070), 2012 (New Phytologist, 193, 150-164)

Climate change implications since the LGM





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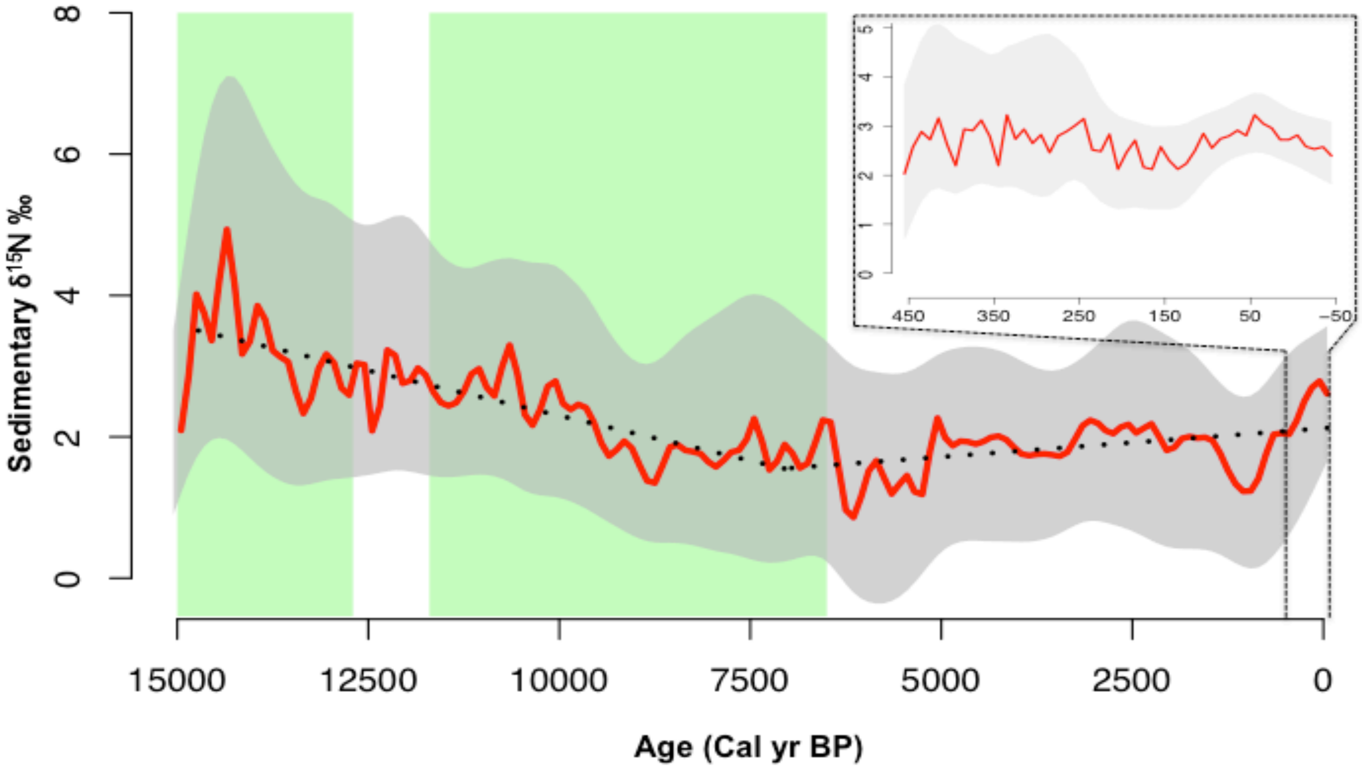
Interactions between nutrient affect species diversity patterns

- Riech (2009) showed that interaction between carbon and nitrogen can affect species diversity patterns.

- In fact, increasing CO2 can mitigate species due to nitrogen enrichment

How might species number variation change with changes in nutrient ratios?

Progressive Nitrogen Limitation

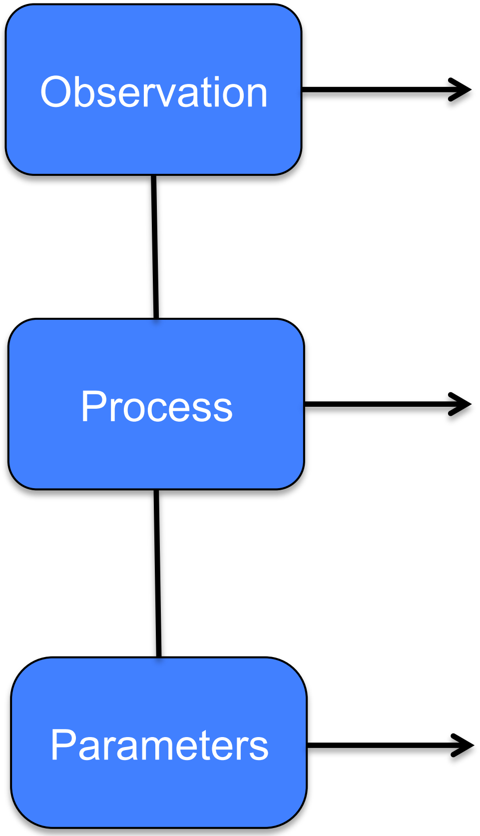


From McLauchlan et al. (2013)

Resource-consumer model

Counts of Species

$$\frac{dR}{dt} = \lambda_R - \left[h(S) + \mu_R\right]R$$
$$\frac{dS}{dt} = \left[f(\lambda_S, R, S) - g(\mu_S, R, S)\right]S$$

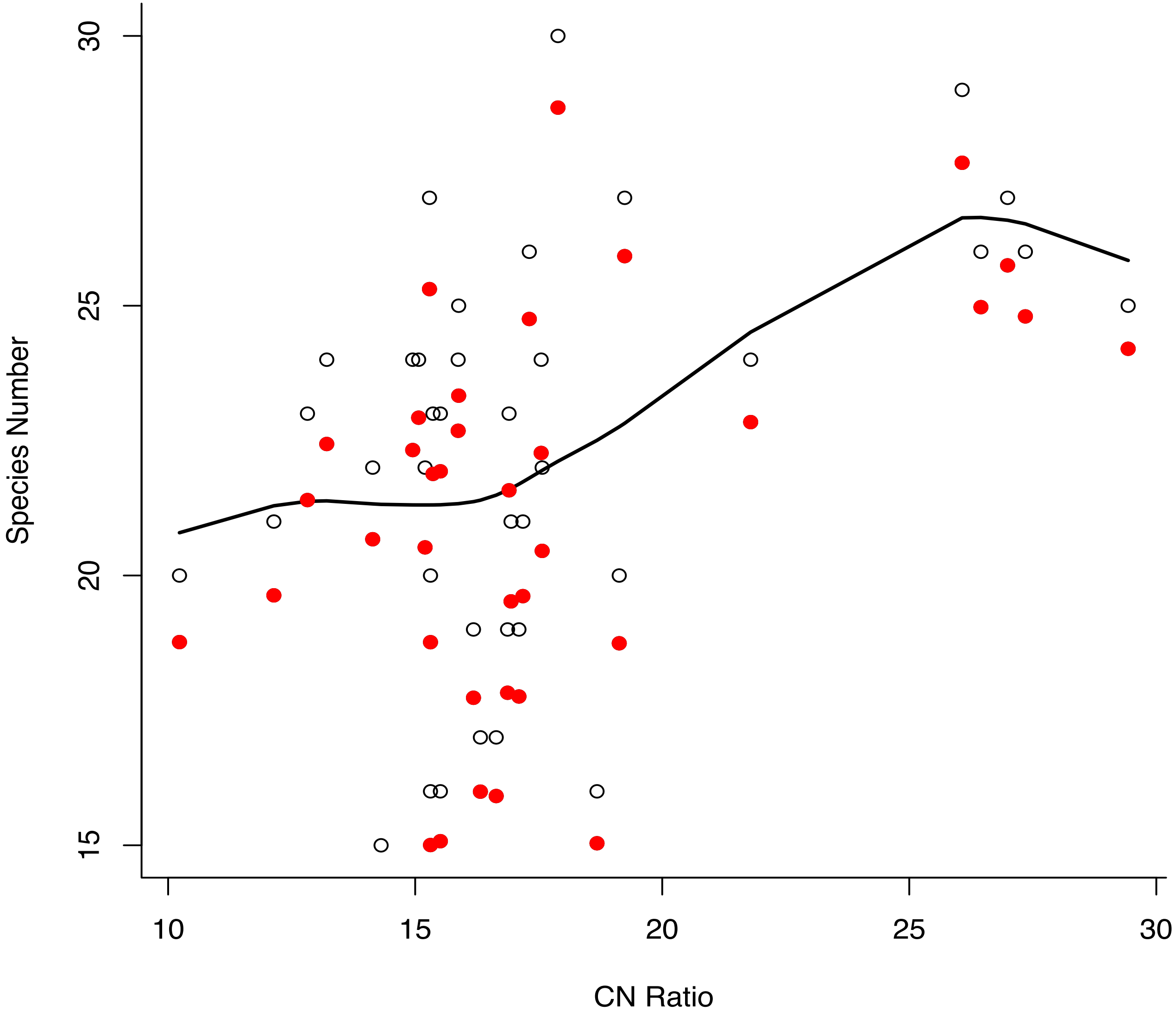


Observation → **Poisson** (Measurement Error)

Process → **Normal** (Process Error)

Parameters → Parameter Error

Effects of CN Ratio on Diversity



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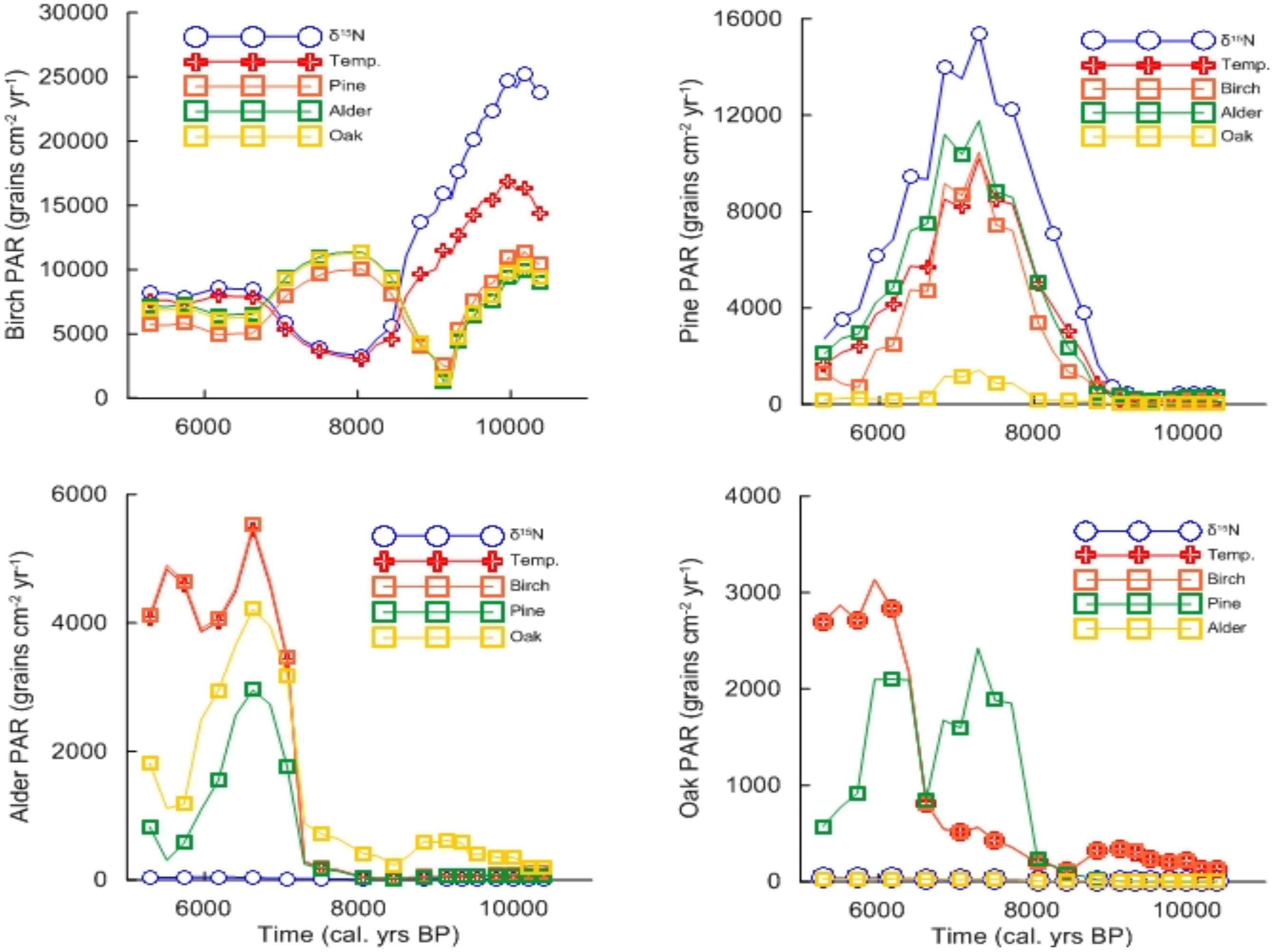
Idiosyncratic plant dynamics under climate change



Challenges

- To understand species distribution and abundances we certainly can’t ignore uncertainty
- Dealing with measurement and/or process error is inherent in ecological systems
- We need biological relevant (as well as biological motivated) mathematical approaches to promulgating predictions about climate change

Acknowledgements

Plants in the Holocene:
Lizzy Jeffers; Stephen Brooks; Jenny Watson; Kathy Willis

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Claire Dooley; Anna Kasparson; Jeremy Thomas; Tom Brereton; David Roy;

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Metapopulation microcosms:
Jim Bull; David French; Nicola Pickup; Alan Hastings; Mike Hassell; Julia Hunt; Chloe Strevens; Thomas Tschuelin; Brian Pickett

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Questions?

“Einstein was a giant. His head was in the clouds but his feet were on the ground. Those of us who are not so tall have to choose!” (RP Feynman)