

Inferring processes of ecological community dynamics with temporal data



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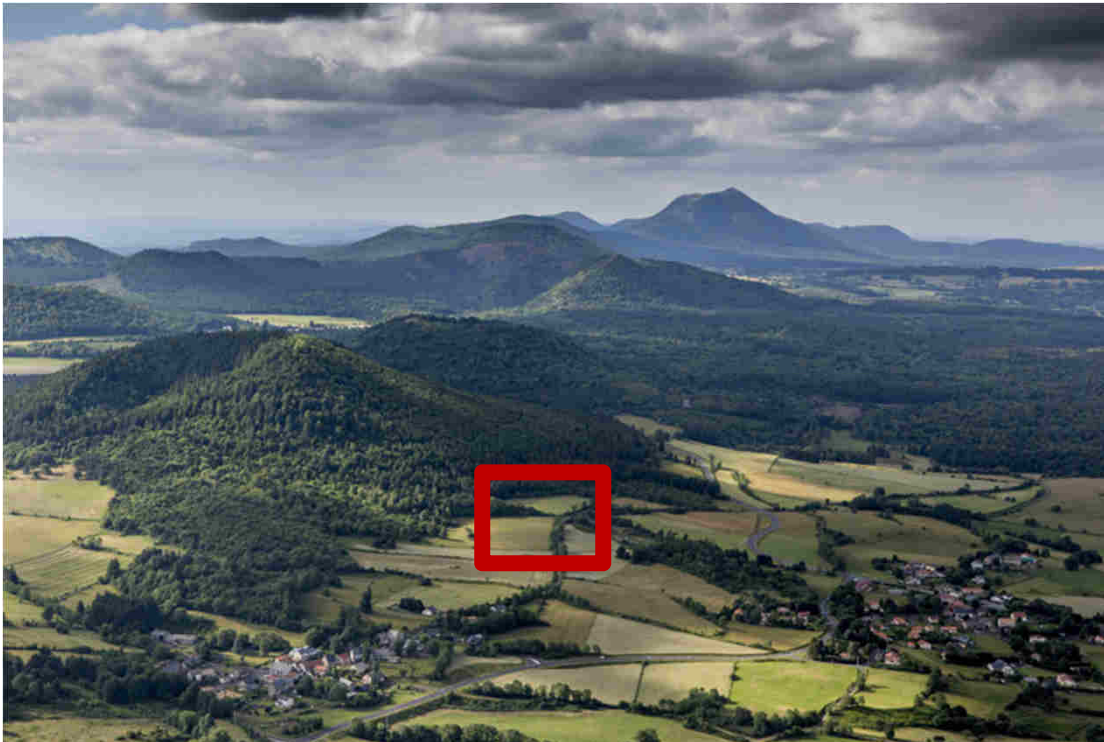
Clermont-Ferrand – 11/2018

Ecological motivation

Quantifying the relative impact of various ecological processes
on biodiversity dynamics

Ecological motivation

Quantifying the relative impact of various ecological processes
on biodiversity dynamics



- dispersal
- climatic filters
- pedological filters
- management filters
- competition/facilitation
- multi-trophic interactions
- biogeographical context
- historical contingency
- demographic stochasticity
- ...

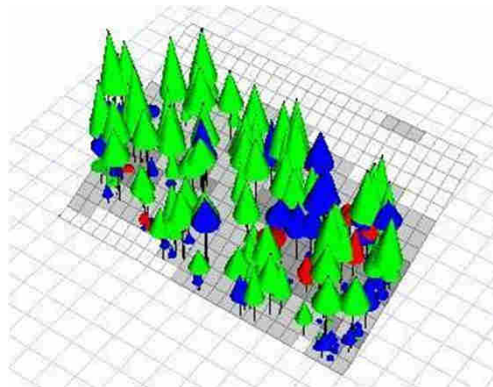
Modelling challenge

Making sense of heterogeneous data

(spatial scale, temporal scale, organization scale, retro-actions...

see the notion of complex adaptive systems)

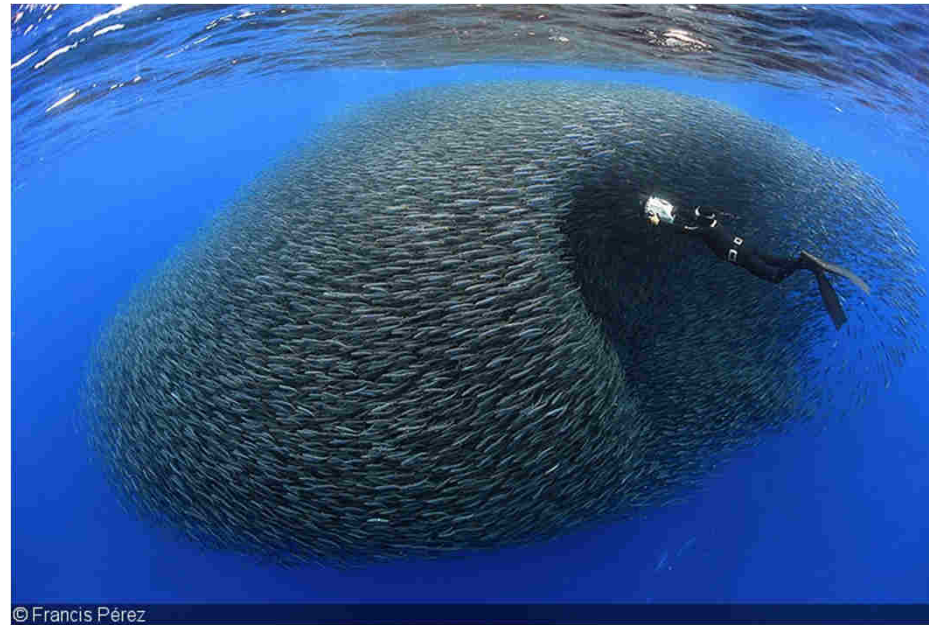
Individual-based model (IBM)



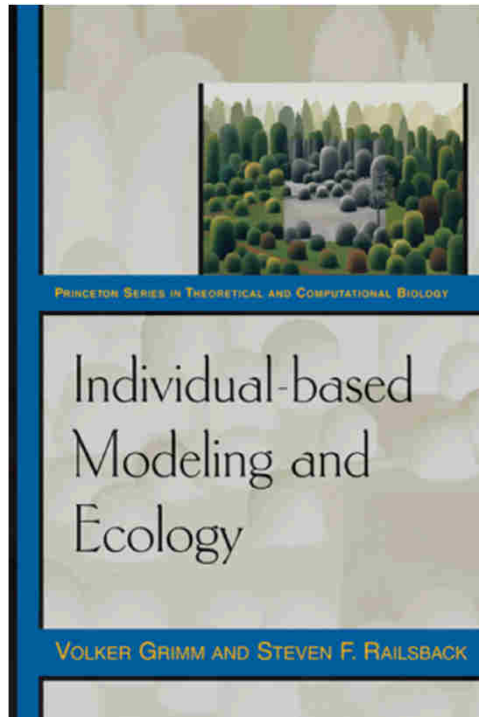
Outline

- **IBMs in ecology – focus on biodiversity dynamics and on my own work**
- **Temporal data and IBMs – two examples**
- **Perspectives – environmental variability and biodiversity dynamics**

IBMs in ecology



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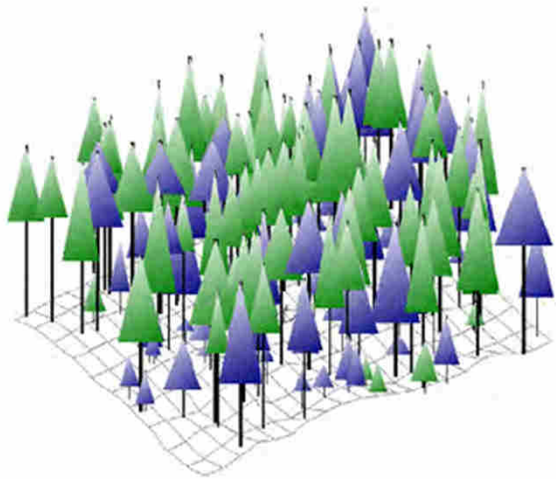
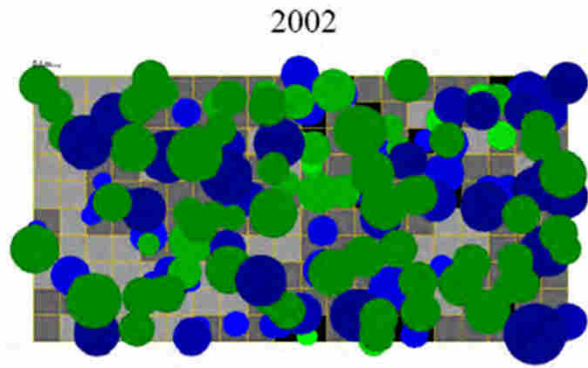


PRINCETON SERIES IN THEORETICAL AND COMPUTATIONAL BIOLOGY

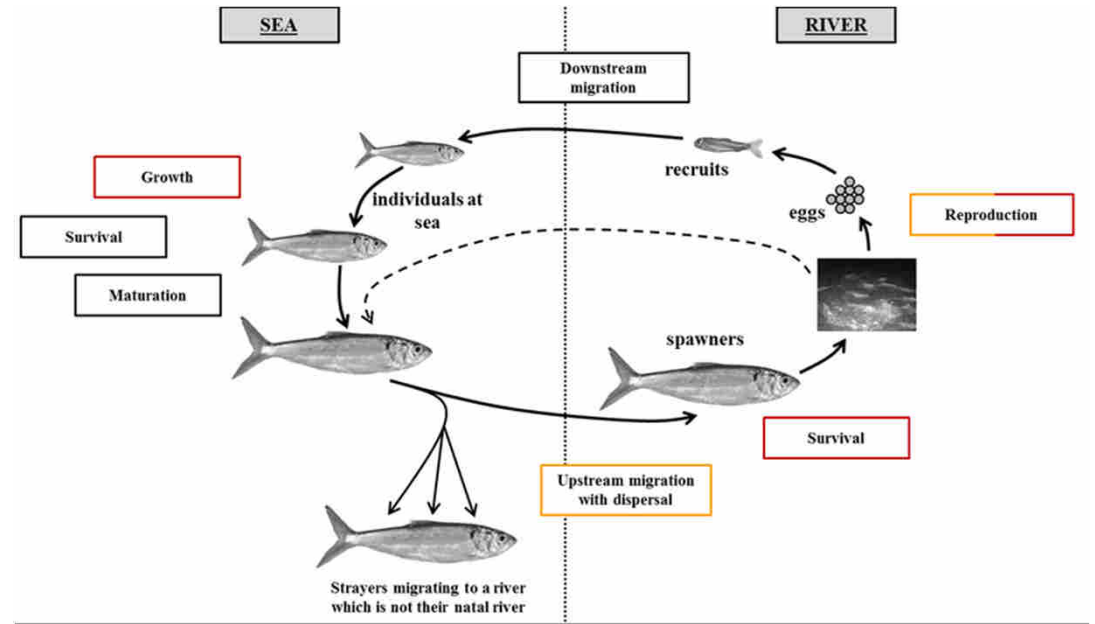
Individual-based
Modeling and
Ecology

VOLKER GRIMM AND STEVEN F. RAILSBACK

IBMs in ecology



Samsara2 forest model (Courbaud et al.)



GR3D fish model (Rougier et al.)

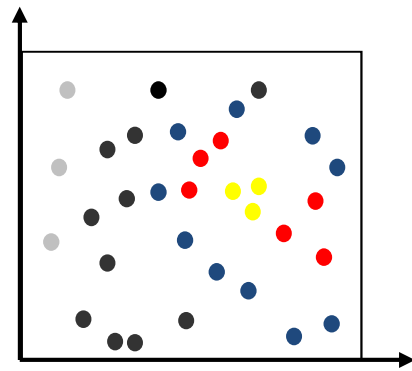
IBMs in ecology

« Pattern-oriented modelling »: which rules lead to given collective patterns?
Grimm et al. Science 2005

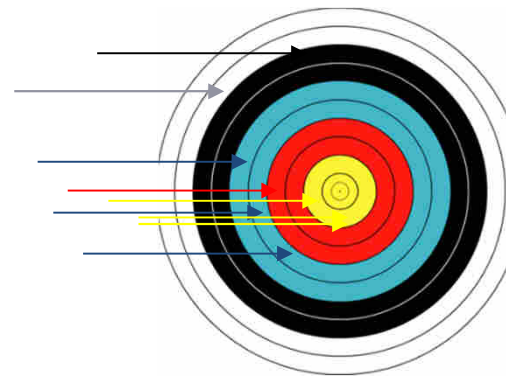


IBMs in ecology

Calibration: optimization techniques, Approximate Bayesian Computation
Tavaré et al. Genetics 1997

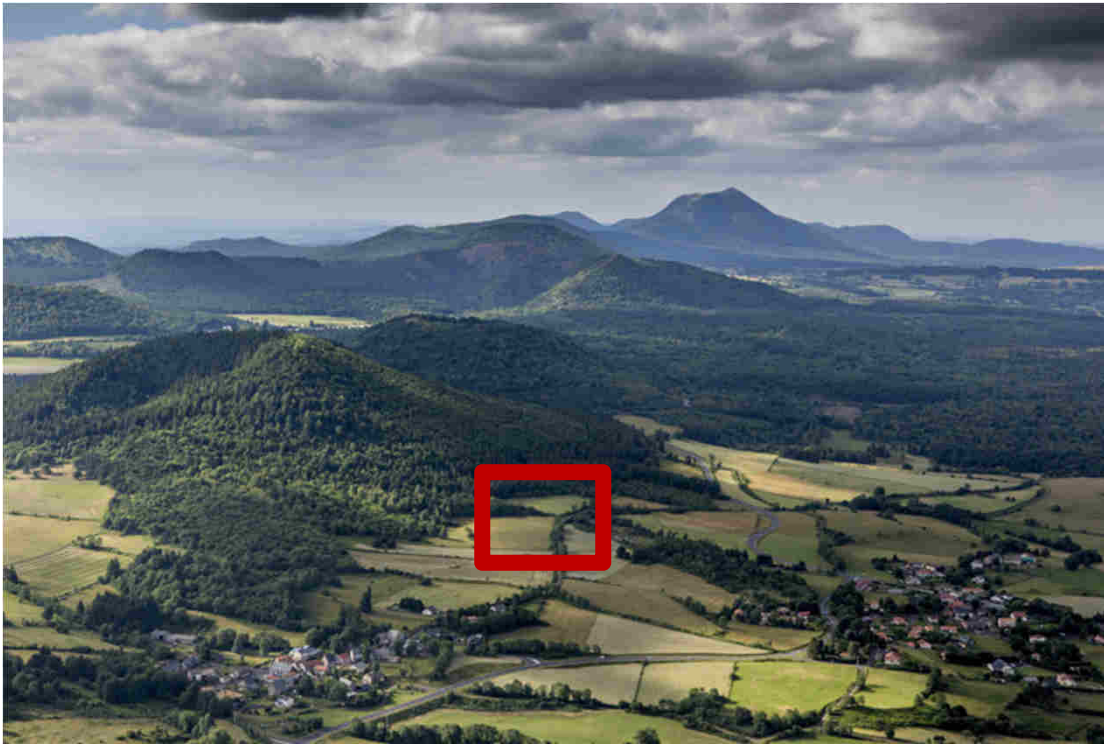


Parameter space



Data-model match

IBMs of biodiversity dynamics: the neutral model



-dispersal

-climatic filters

-pedological filters

-management filters

-competition/facilitation

-multi-trophic interactions

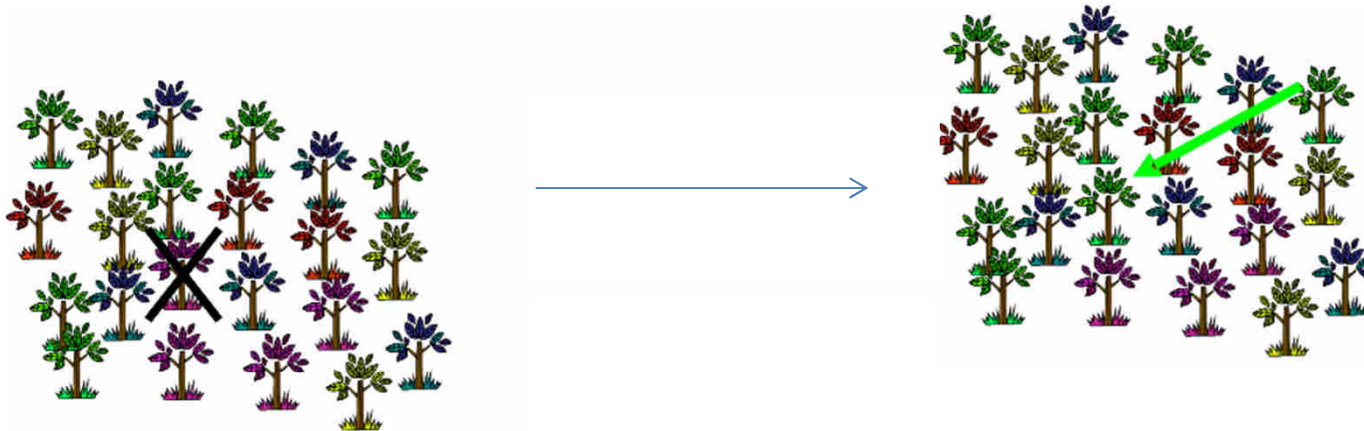
-biogeographical context

-historical contingency

-demographic stochasticity

...

IBMs of biodiversity dynamics: the neutral model



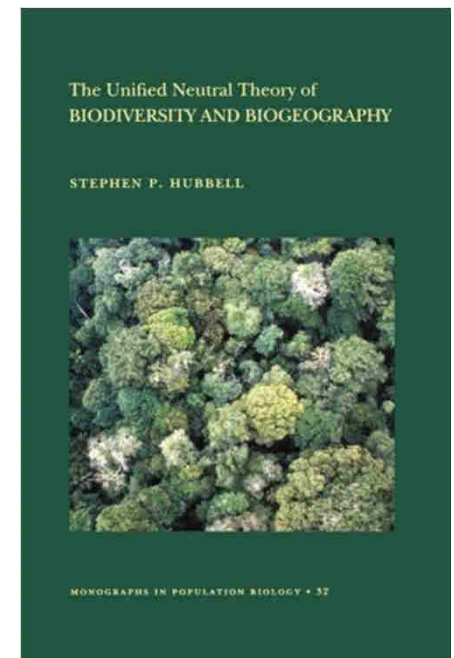
Discrete time model:

$$P(\text{individual } i \text{ dies}) = 1 / N$$

$$P(\text{individual } j \text{ replaces the dead individual}) = (1-m) / (N-1)$$

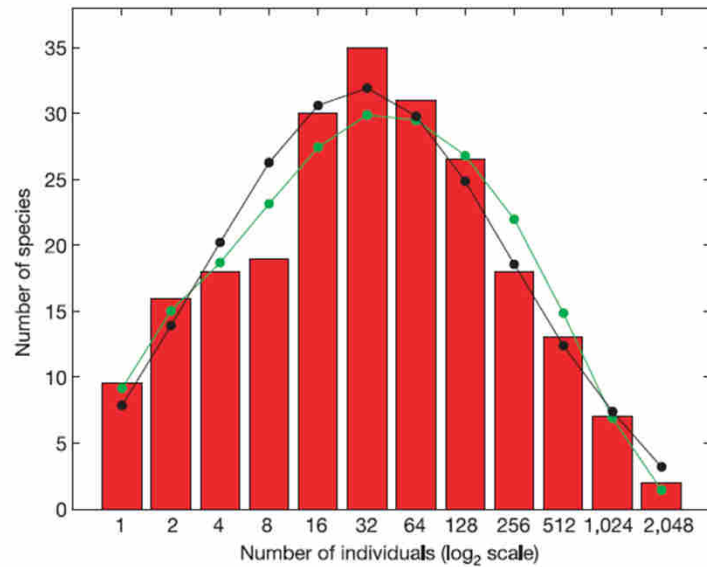
$$P(\text{immigrating individual replaces the dead individual}) = m$$

-> a lot of available analytical results.



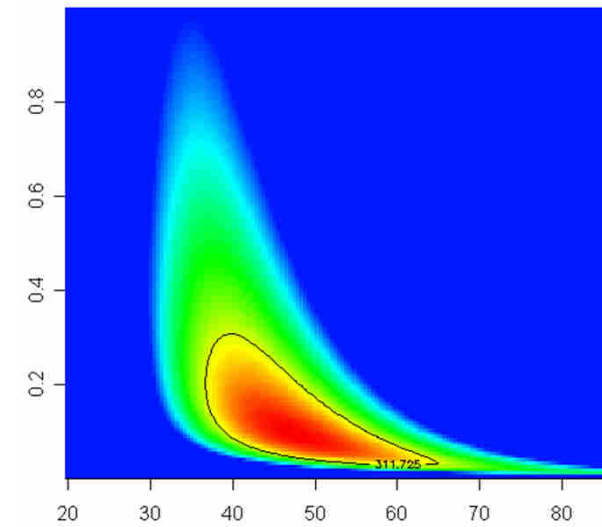
IBMs of biodiversity dynamics: the neutral model

The neutral model fits reasonably well empirical species abundance distributions



Volkov et al. Nature 2003

Immigration: m

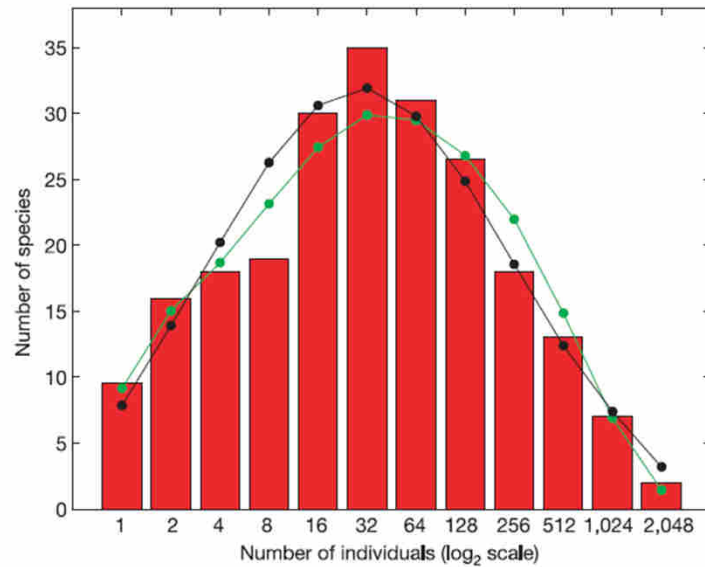


Regional diversity: θ

Jabot et al. Oikos 2008

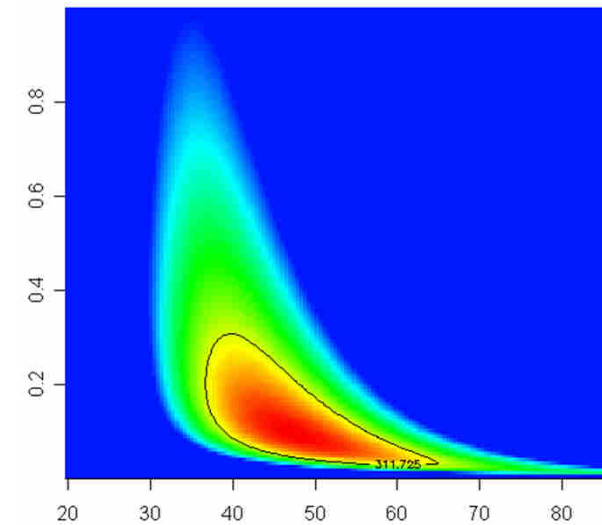
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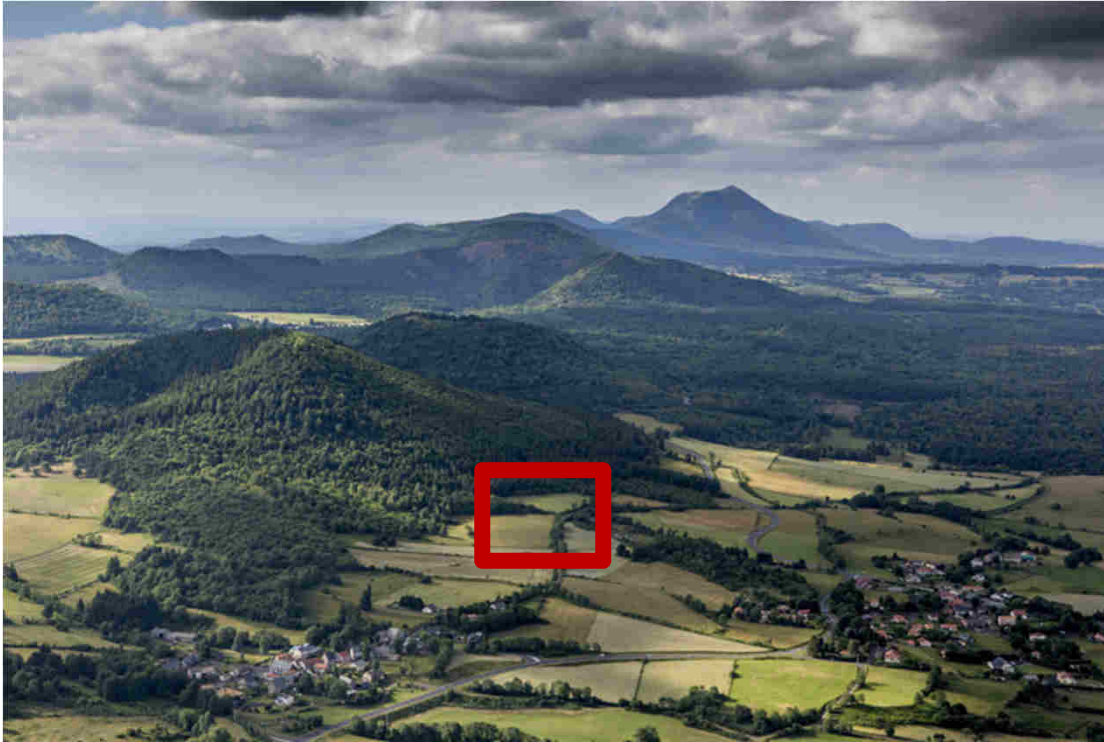


Regional diversity: θ

Jabot et al. Oikos 2008

It also fits well the spatial turn-over of species (Condit et al. Science 2002) and community phylogenetic patterns (Jabot & Chave Ecol. Lett. 2009)

IBMs of biodiversity dynamics: the neutral model



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-management filters

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-multi-trophic interactions

-biogeographical context

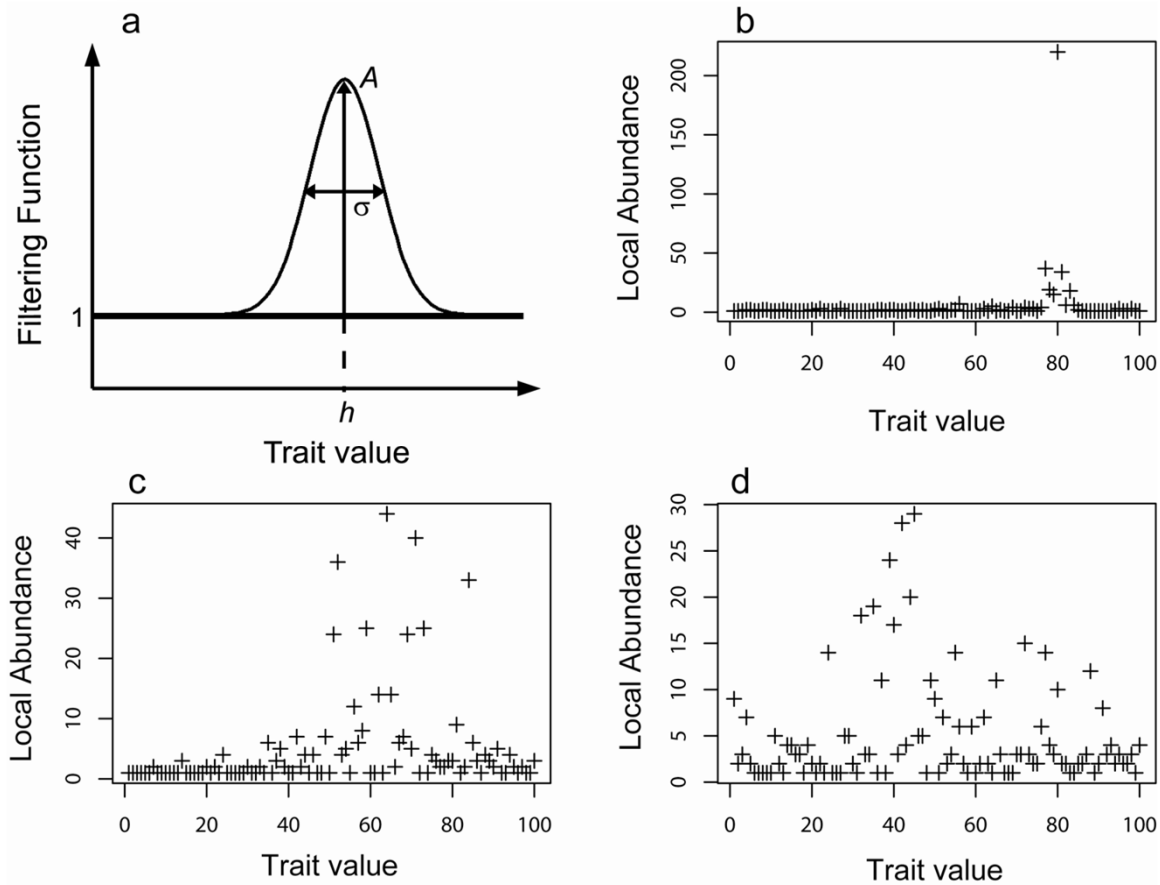
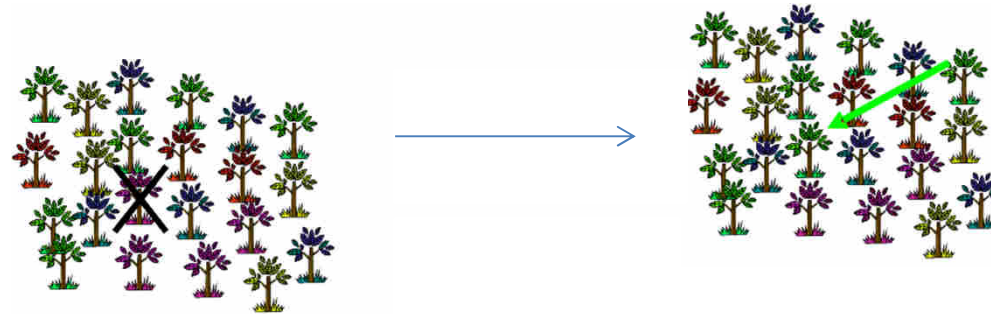
-historical contingency

-demographic stochasticity

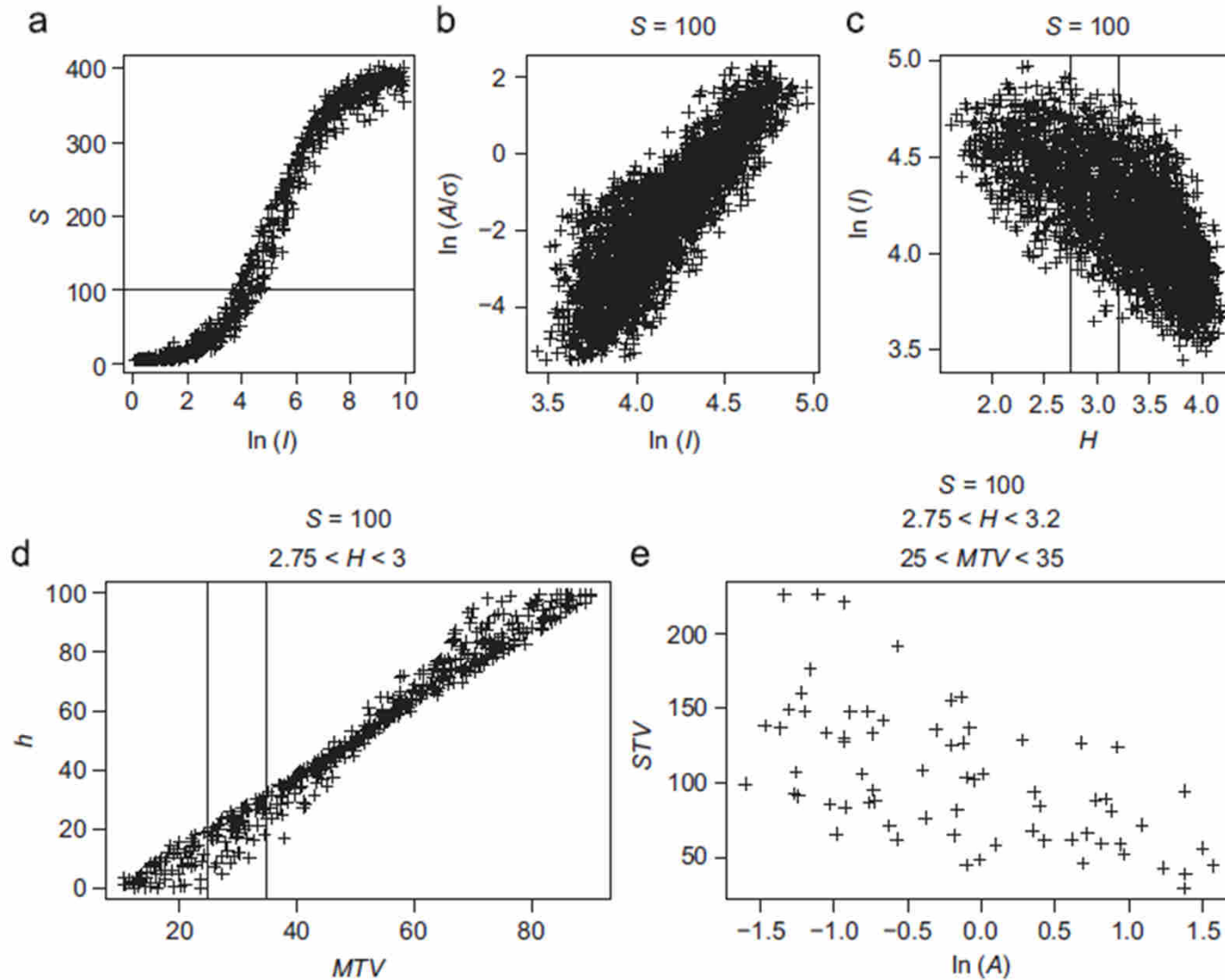
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Including other processes in the model?

Beyond the neutral model: trait-based environmental filtering

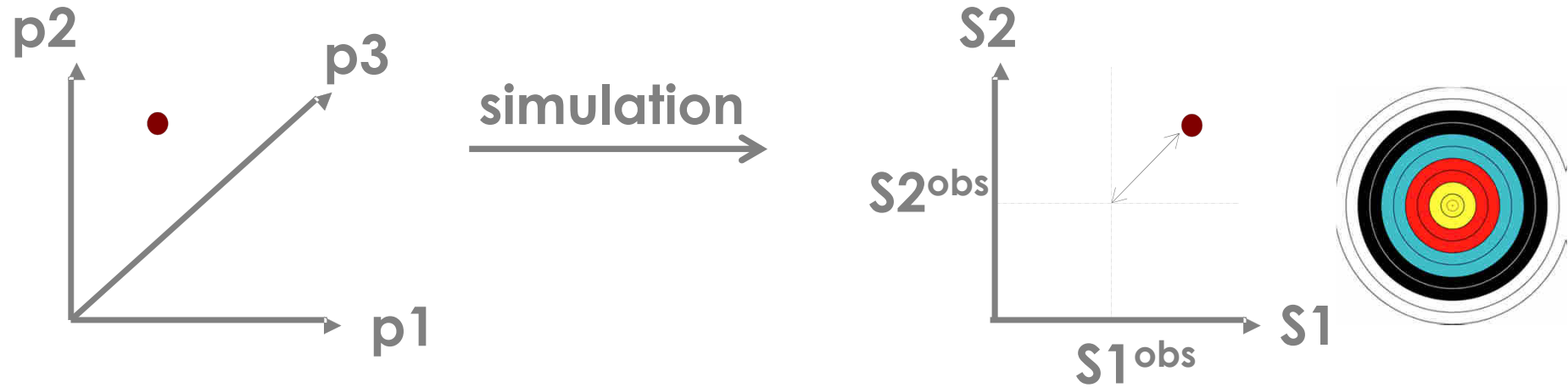


Beyond the neutral model: trait-based environmental filtering



Beyond the neutral model: trait-based environmental filtering

Approximate Bayesian Computation



Beyond the neutral model: trait-based environmental filtering

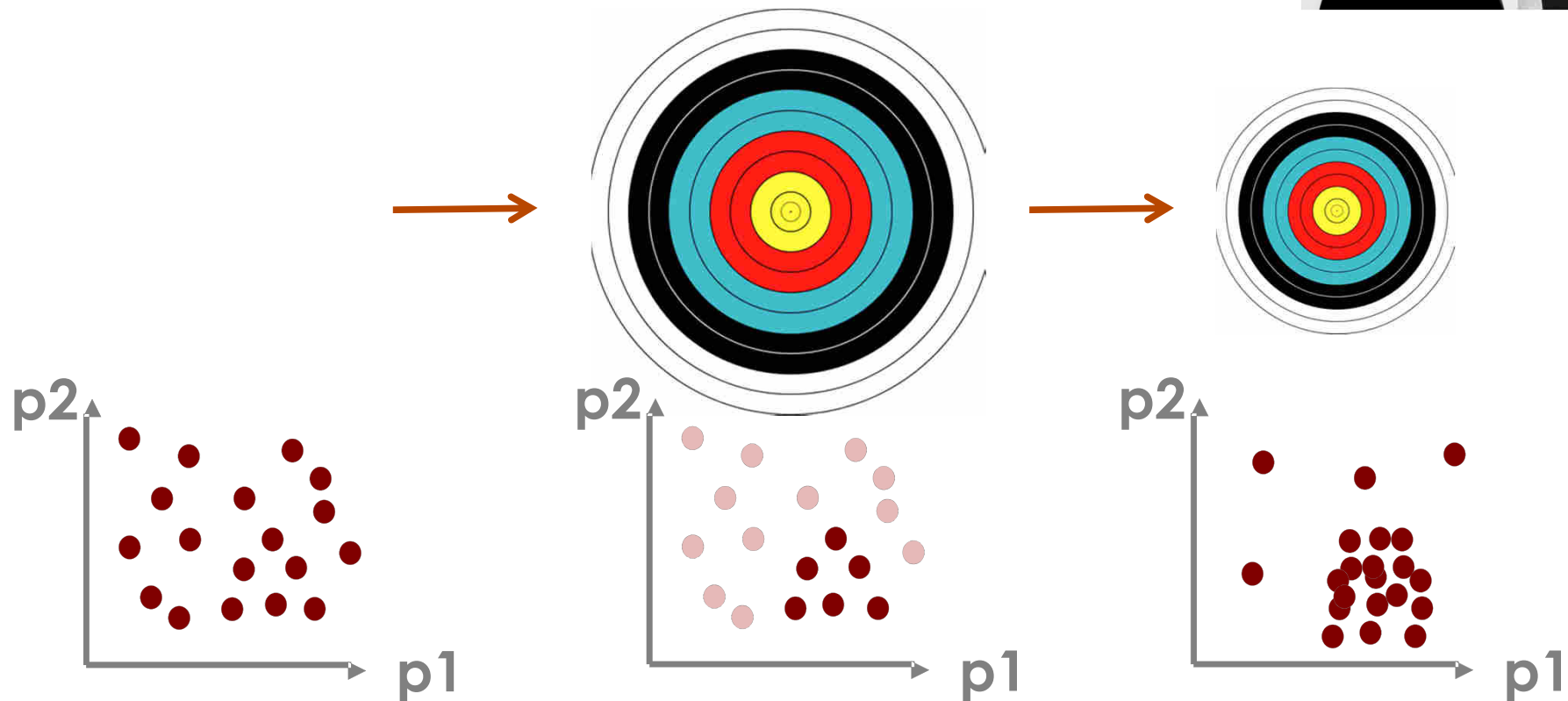
Approximate Bayesian Computation



Beyond the neutral model: trait-based environmental filtering

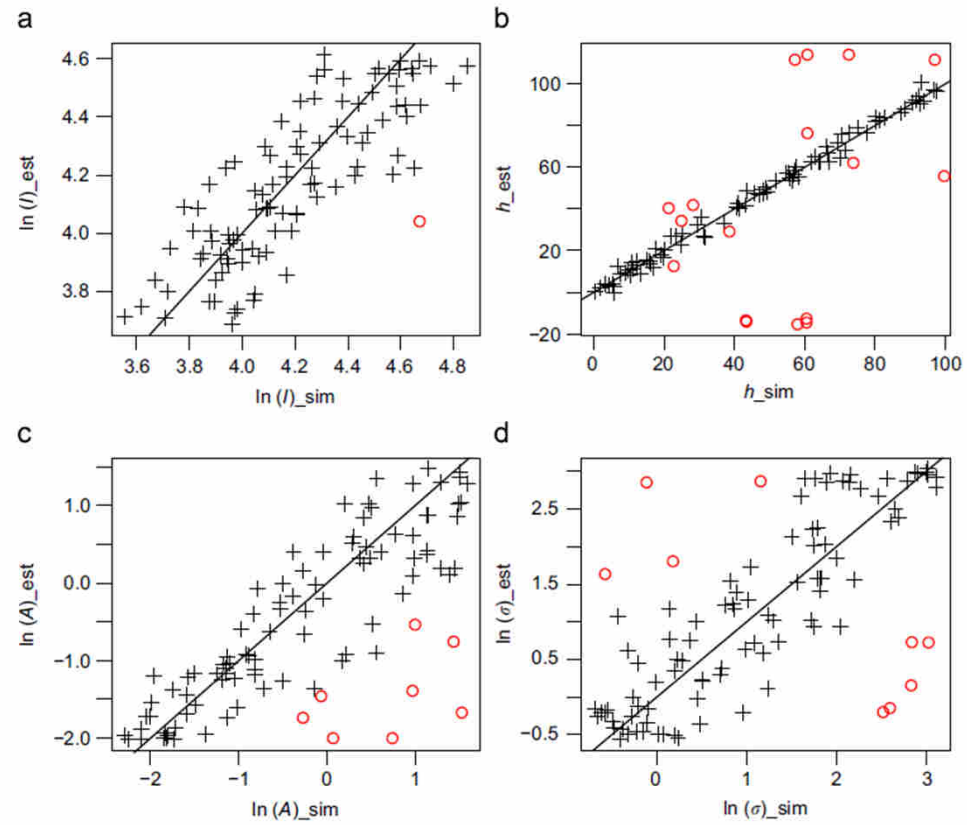


Approximate Bayesian Computation – sequential/emulation techniques
(Lenormand et al. Comput. Stat. 2013, Jabot et al. arXiv 2014, Lagarrigues et al. Ecol. Mod. 2015)

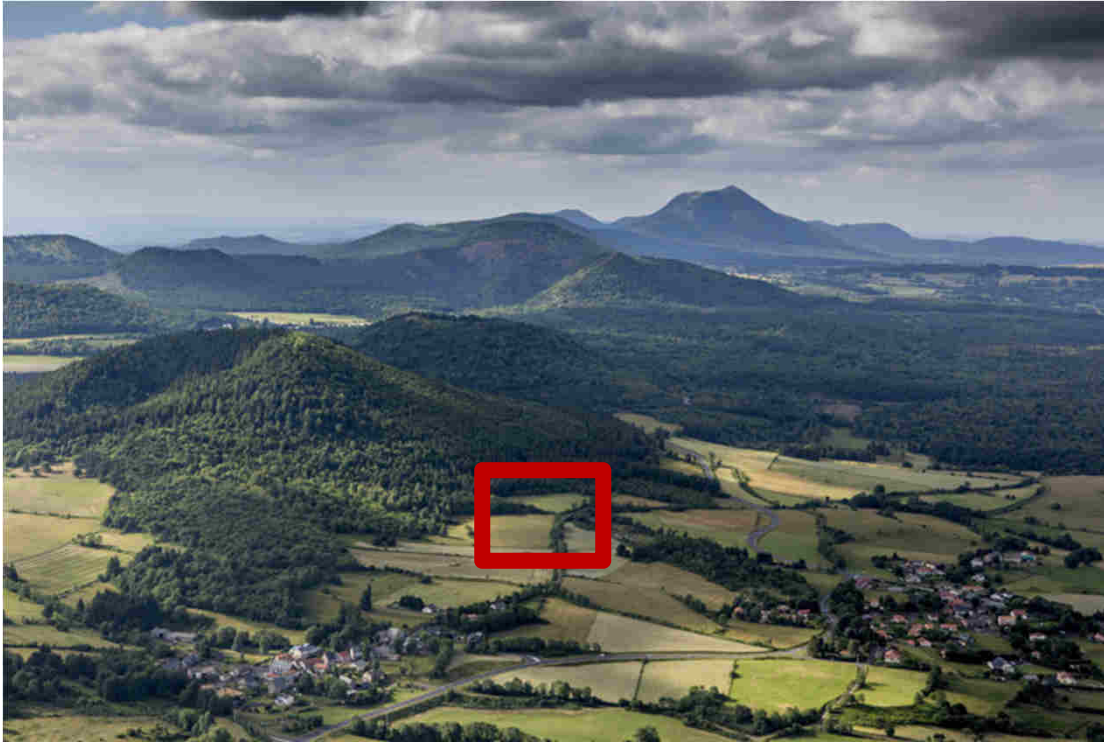


→ package  EasyABC - Jabot et al. Meth. Ecol. Evol. 2013

Beyond the neutral model: trait-based environmental filtering



Beyond the neutral model: trophic interactions



-dispersal

-climatic filters

-pedological filters

-management filters

-competition/facilitation

-multi-trophic interactions

-biogeographical context

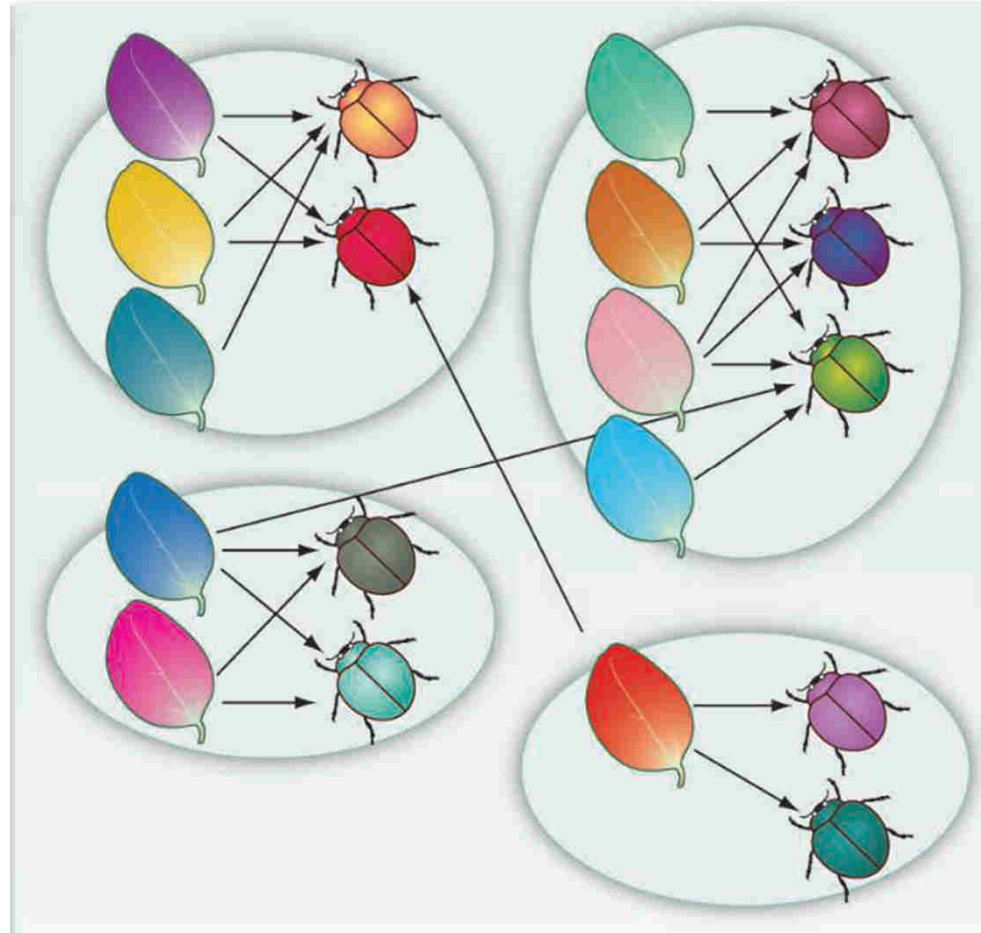
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-demographic stochasticity

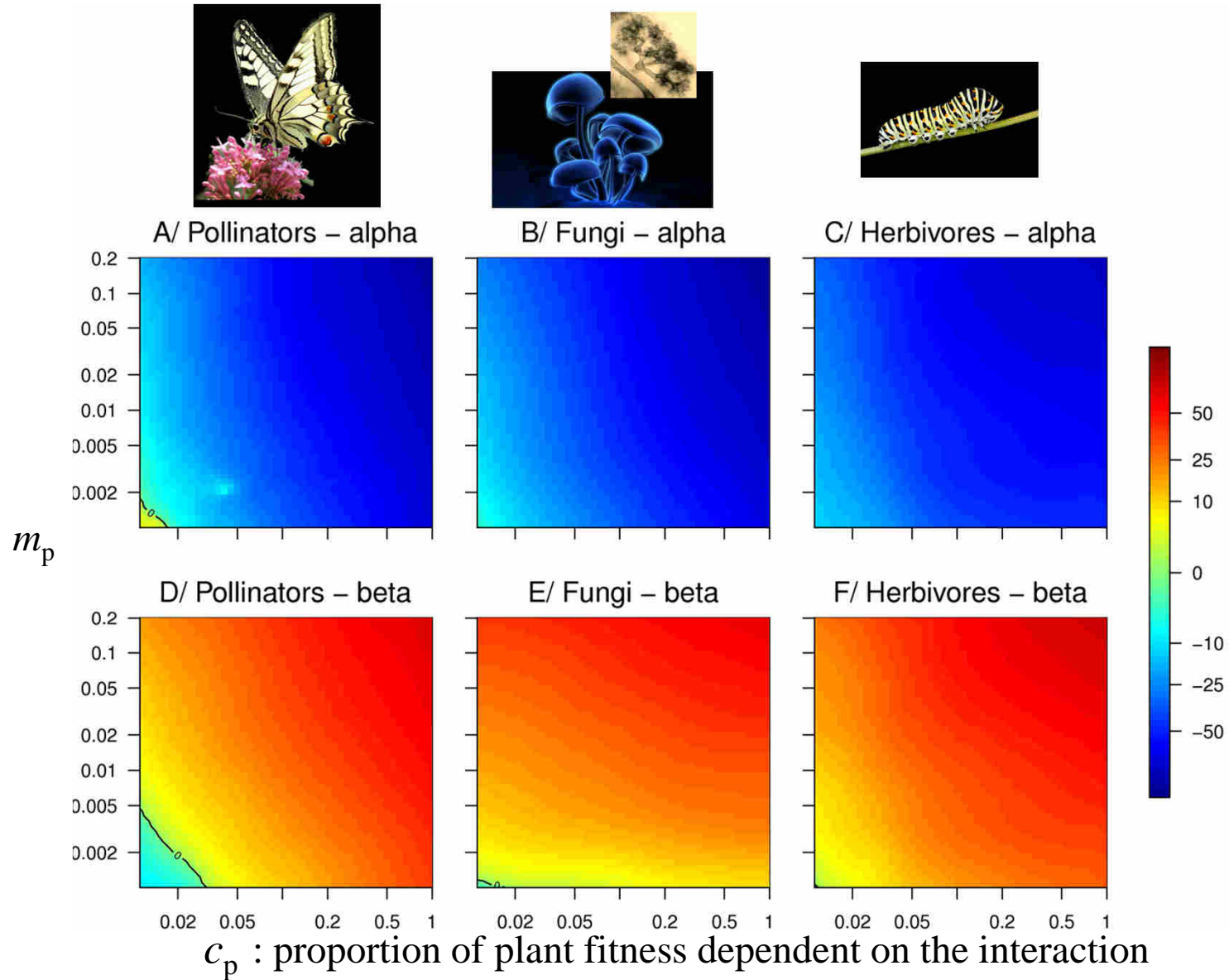
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Including other processes in the model?

Beyond the neutral model: trophic interactions

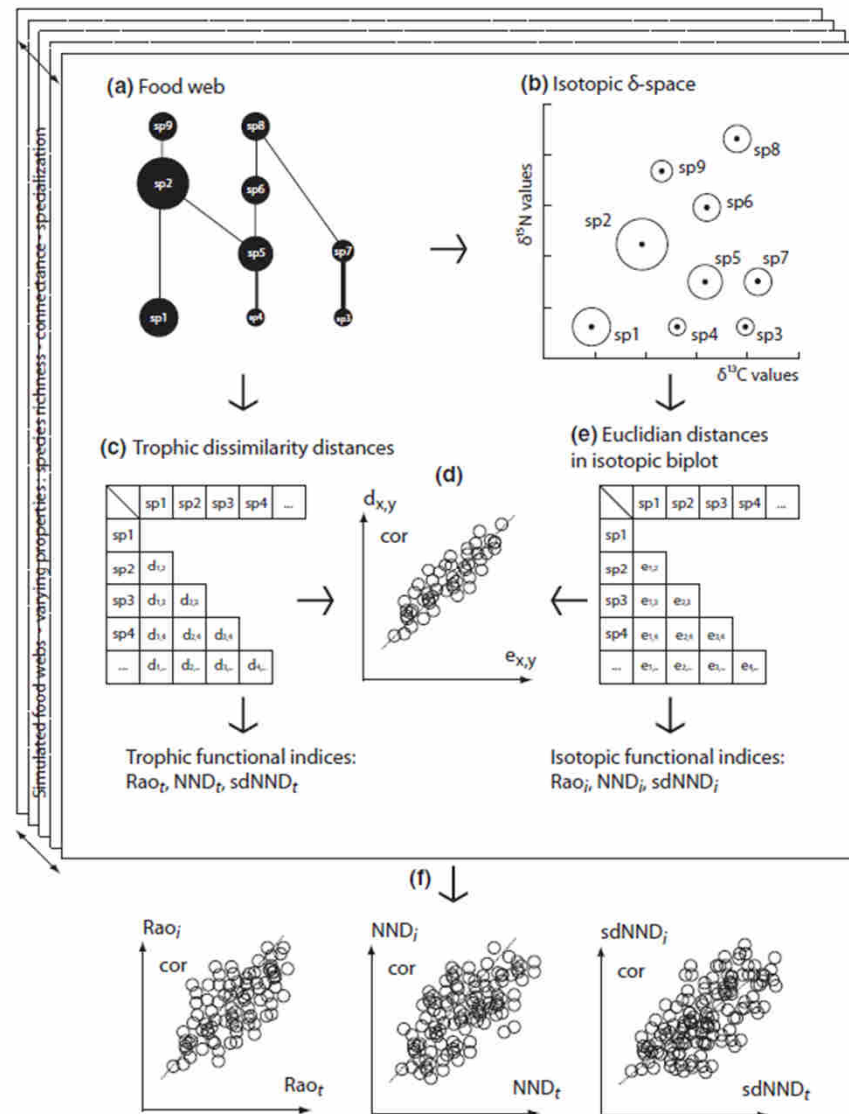


Beyond the neutral model: trophic interactions



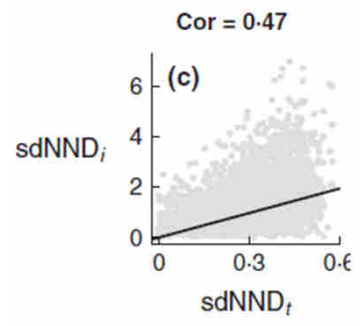
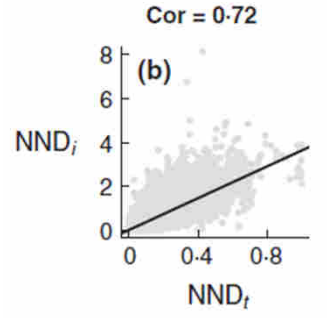
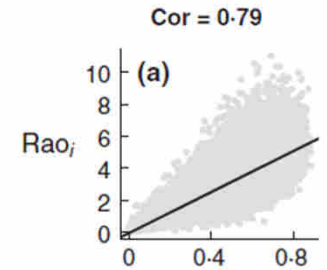
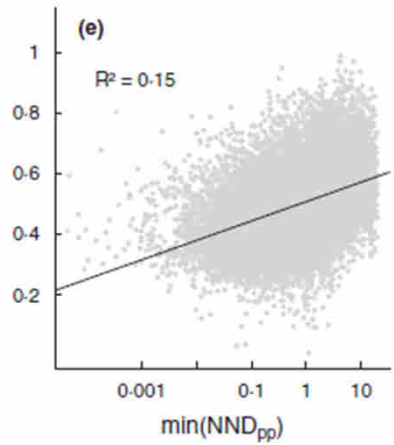
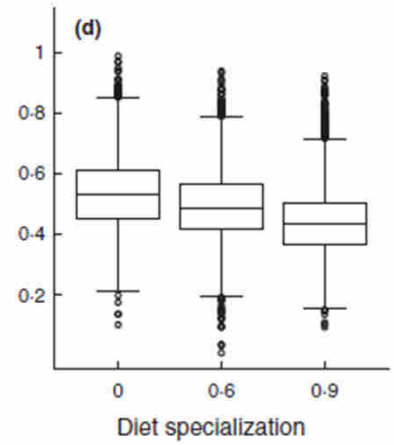
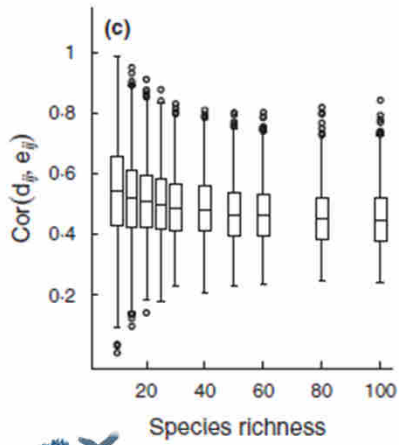
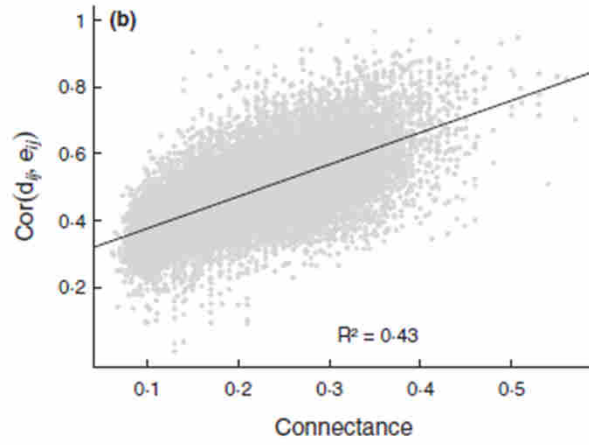
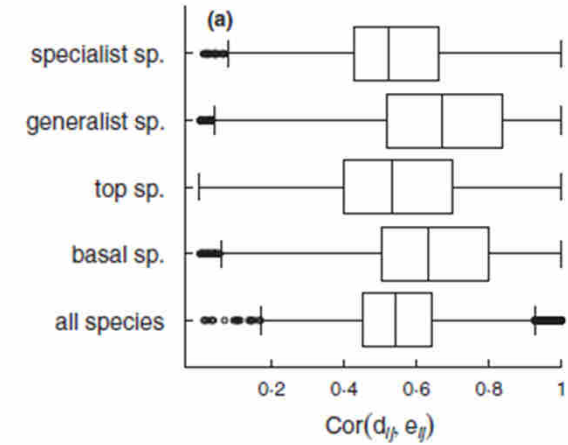
Beyond the neutral model: trophic interactions

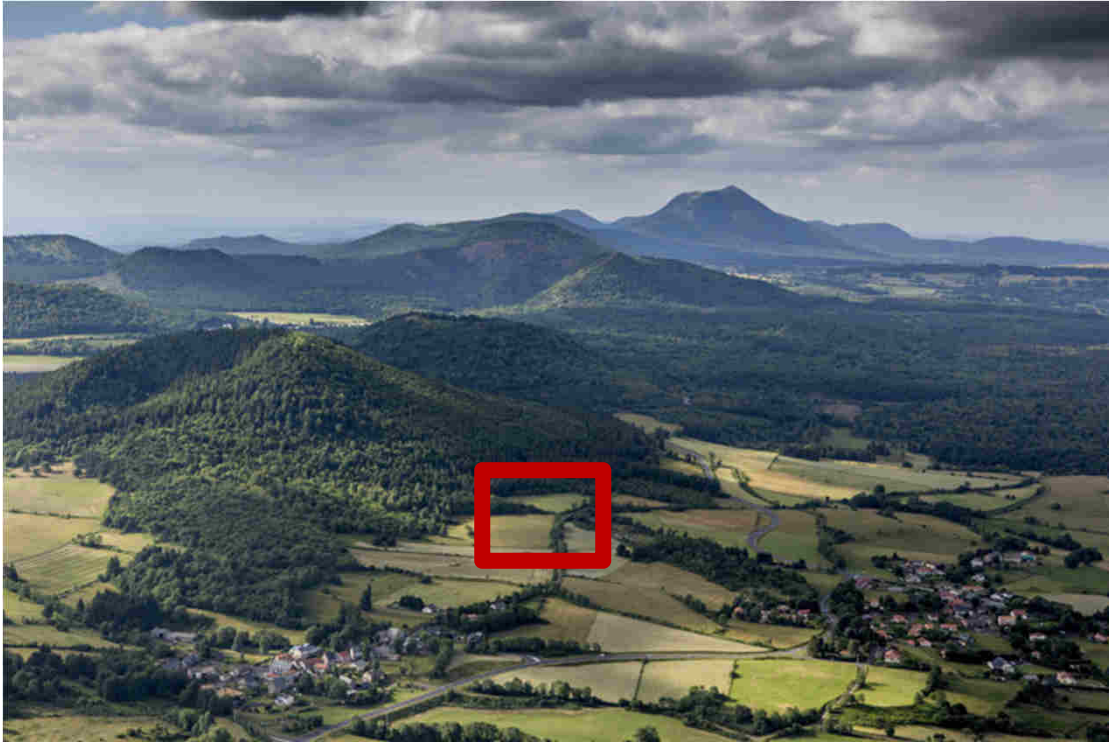
Isotopic information



Beyond the neutral model: trophic interactions

Isotopic information





- dispersal
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- ...

Getting rid of the equilibrium hypothesis

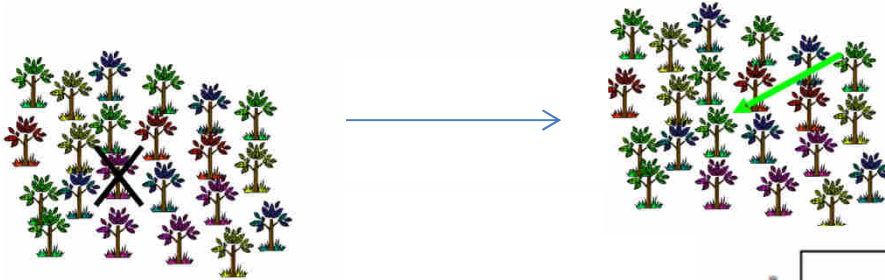
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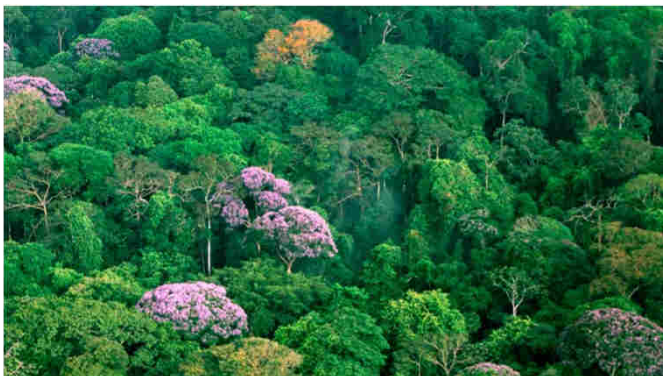
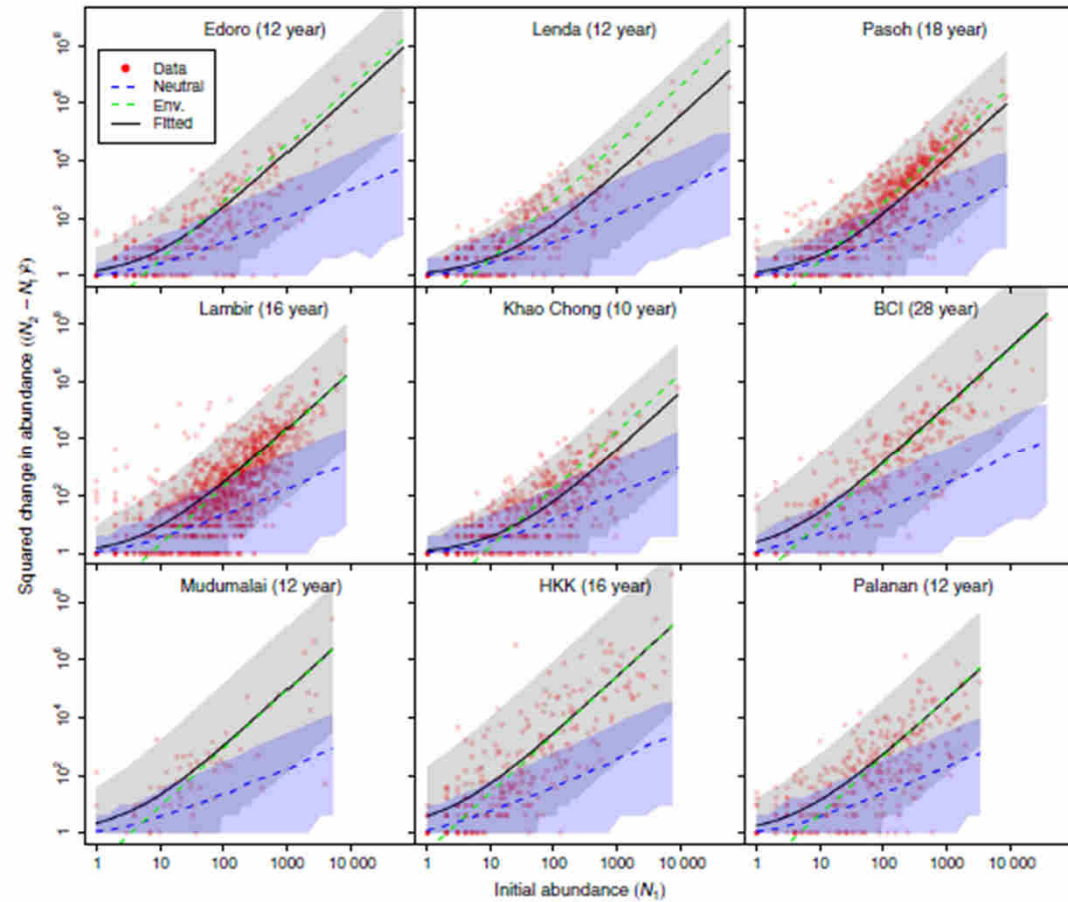
Time-averaged neutral model



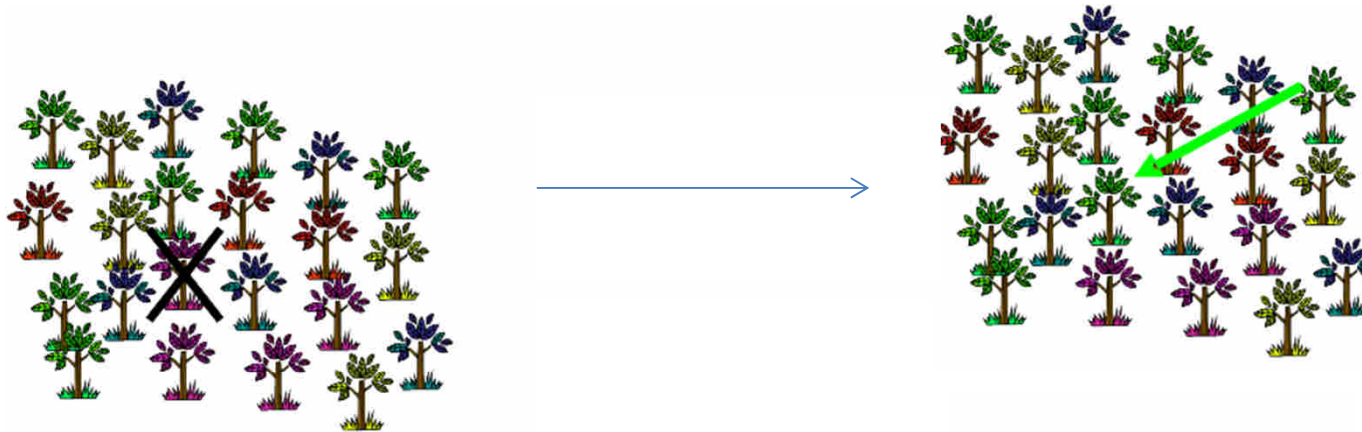
Time-averaged neutral model



- Demographic stochasticity:
 $V [N_i(t+1) | N_i(t)] \sim N_i(t)$
- Environmental stochasticity
 $V [N_i(t+1) | N_i(t)] \sim N_i(t)^2$



Time-averaged neutral model



$$P(k) = \frac{N_k f_k}{\sum_{i=1}^S N_i f_i}$$

Addition:

each species k has a distinct fitness f_k

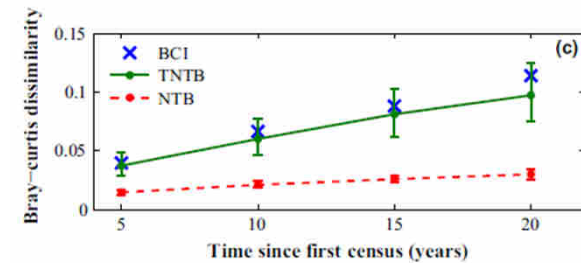
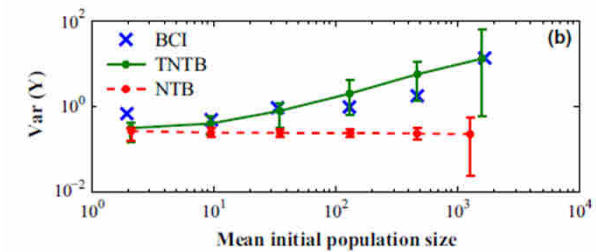
$f_k(t) \sim \text{LogN}(1, A)$

Parameter A : environmental variance

Other « neutral » parameters:

m : immigration rate

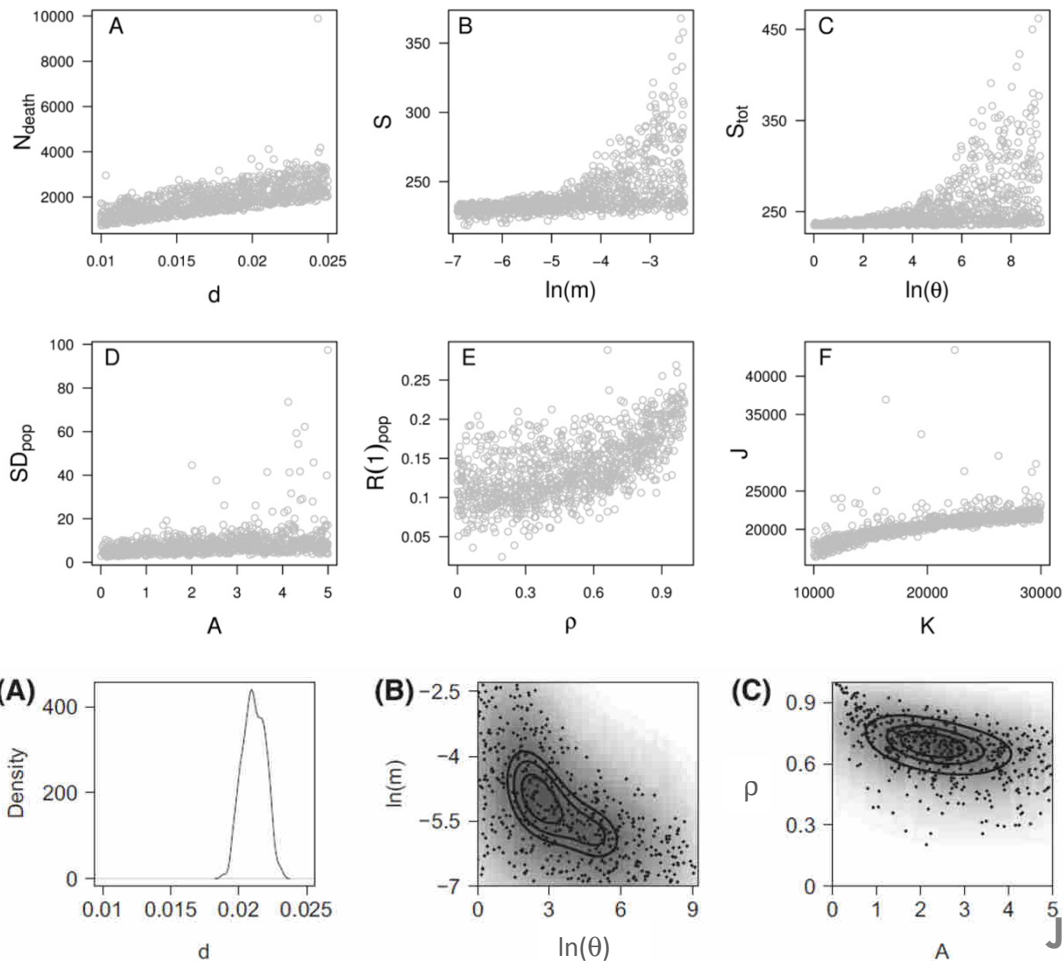
θ : regional diversity



Time-averaged neutral model

1) are the parameters of the TNTB identifiable? (and associated uncertainty?)

- Data: short time series of community composition (here: 3 to 5 dates)
- Inference approach: Approximate Bayesian Computation



Time-averaged neutral model

- 1) are the parameters of the TNTB identifiable? (and associated uncertainty?)
- 2) is the TNTB statistically outperforming NTB?

Time-averaged neutral model

- 1) are the parameters of the TNTB identifiable? (and associated uncertainty?)
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Table 2. Posterior model probabilities for the three datasets. For each dataset, the probability of the selected model is in bold.

Site	BCI	Mudumalai	Pasoh
Demographic stochasticity ($A = 0$ and $\rho = 0$)	0	0	0
Demographic and environmental stochasticity ($\rho = 0$)	0.03	0	0
<u>Demographic and environmental stochasticity with autocorrelation</u>	0.63	0.03	0.0002
<u>Full model with trend in community size (K)</u>	0.35	0.97	0.9998

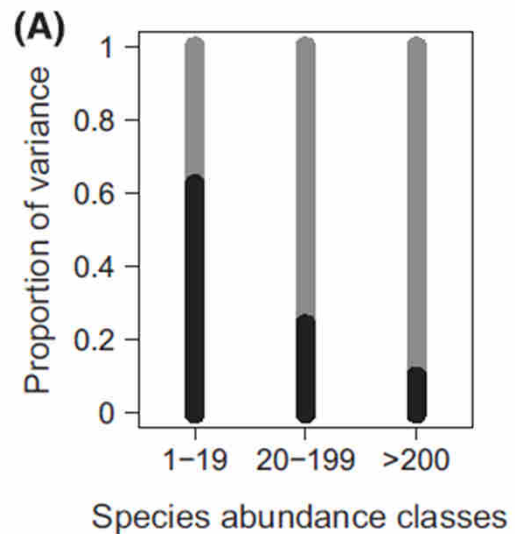
Time-averaged neutral model

- 1) are the parameters of the TNTB identifiable? (and associated uncertainty?)
- 2) is the TNTB statistically outperforming NTB?
- 3) what are the respective impacts of demographic vs environmental stochasticities on community dynamics?

Time-averaged neutral model

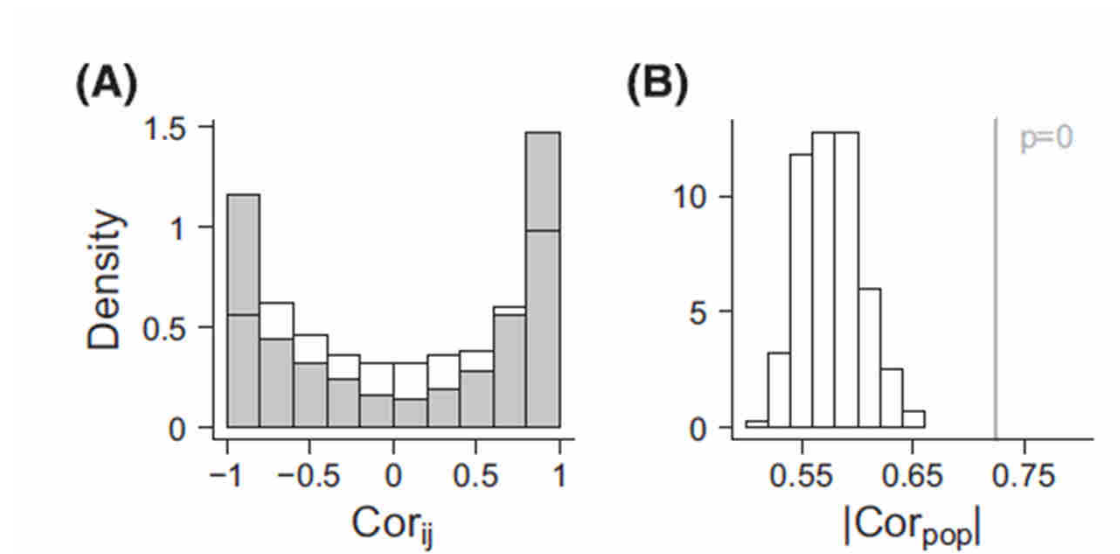
- 1) are the parameters of the TNTB identifiable? (and associated uncertainty?)
- 2) is the TNTB statistically outperforming NTB?
- 3) what are the respective impacts of demographic vs environmental stochasticities on community dynamics?

- Simulation-based computing of the magnitude of demographic vs environmental stochasticity:



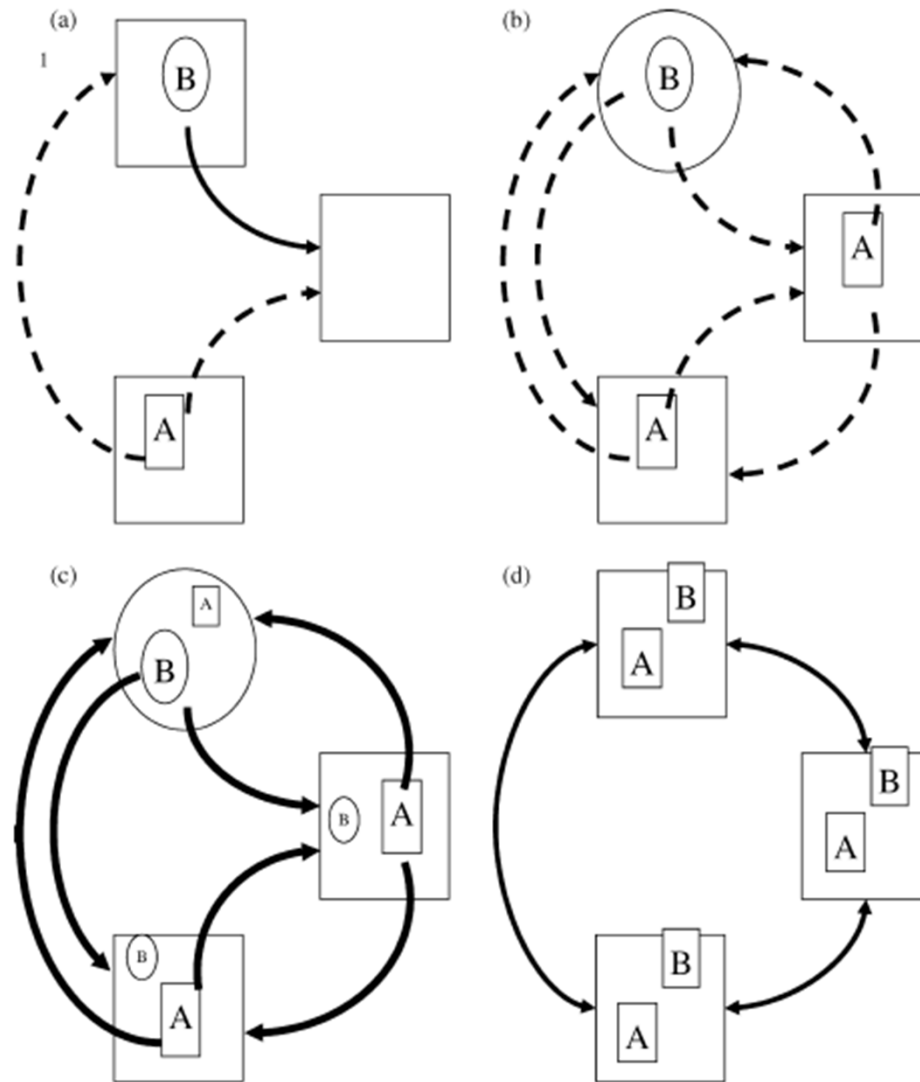
Time-averaged neutral model

- Using TNTB as a null model:

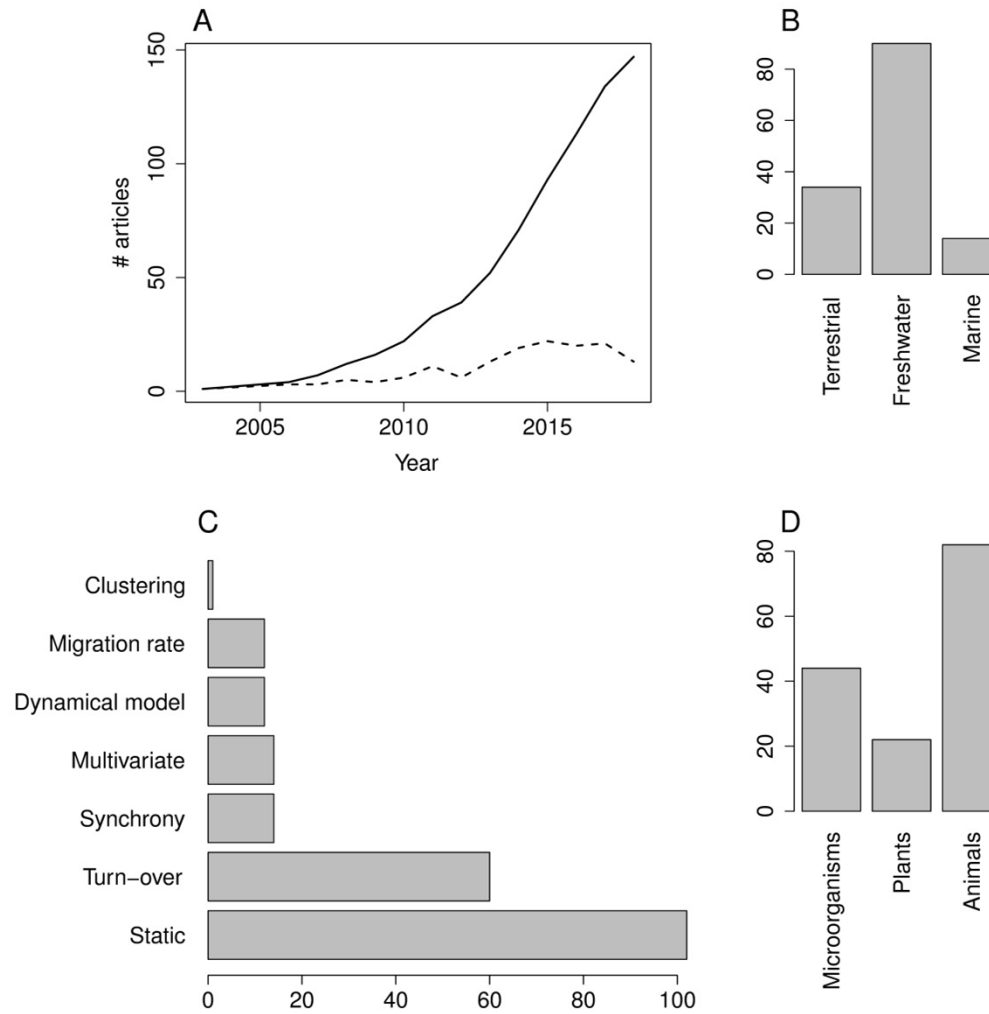


... evidence of non-random correlations between species dynamics.

The metacommunity framework



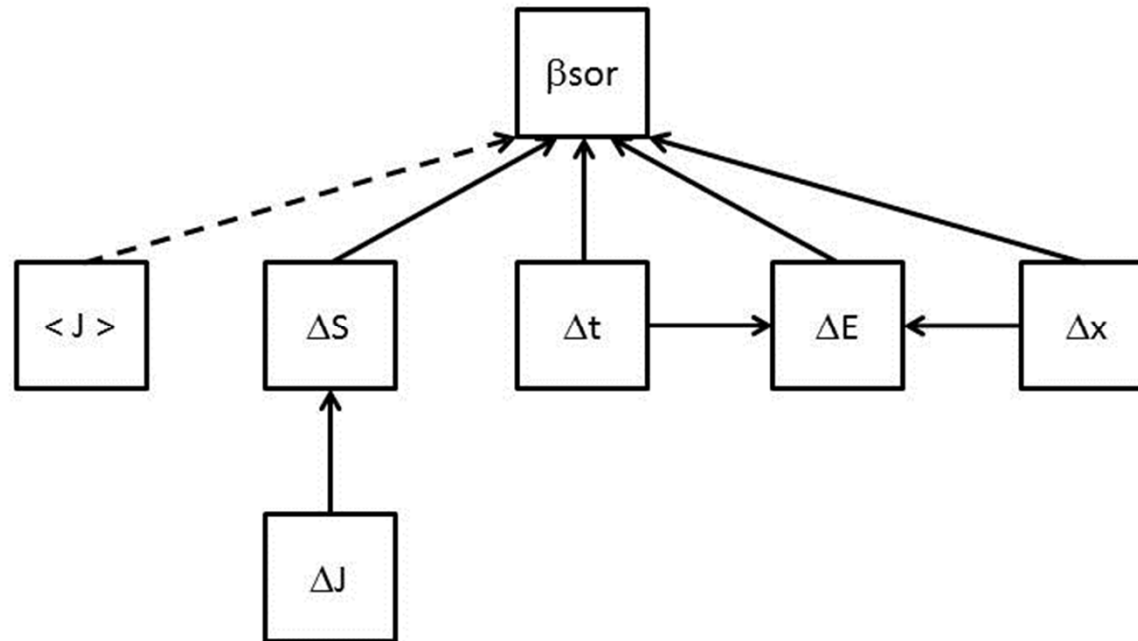
Temporal data are accumulating



A dynamical framework for studying metacommunity dynamics

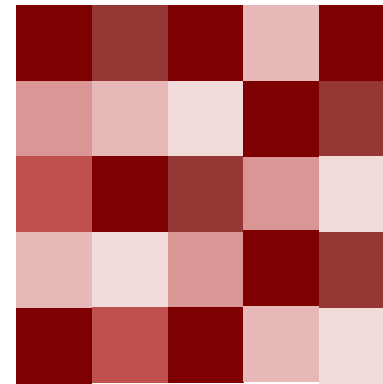
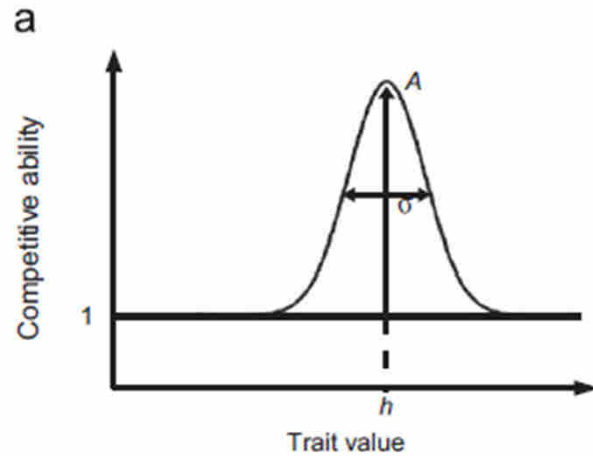
In prep. Joint work with F. Arthaud, S. Blanchet, J. Crabot, T. Datry, P. David, M. Dubart, F. Laroche, F. Massol, F. Munoz

A dynamical framework for studying metacommunity dynamics



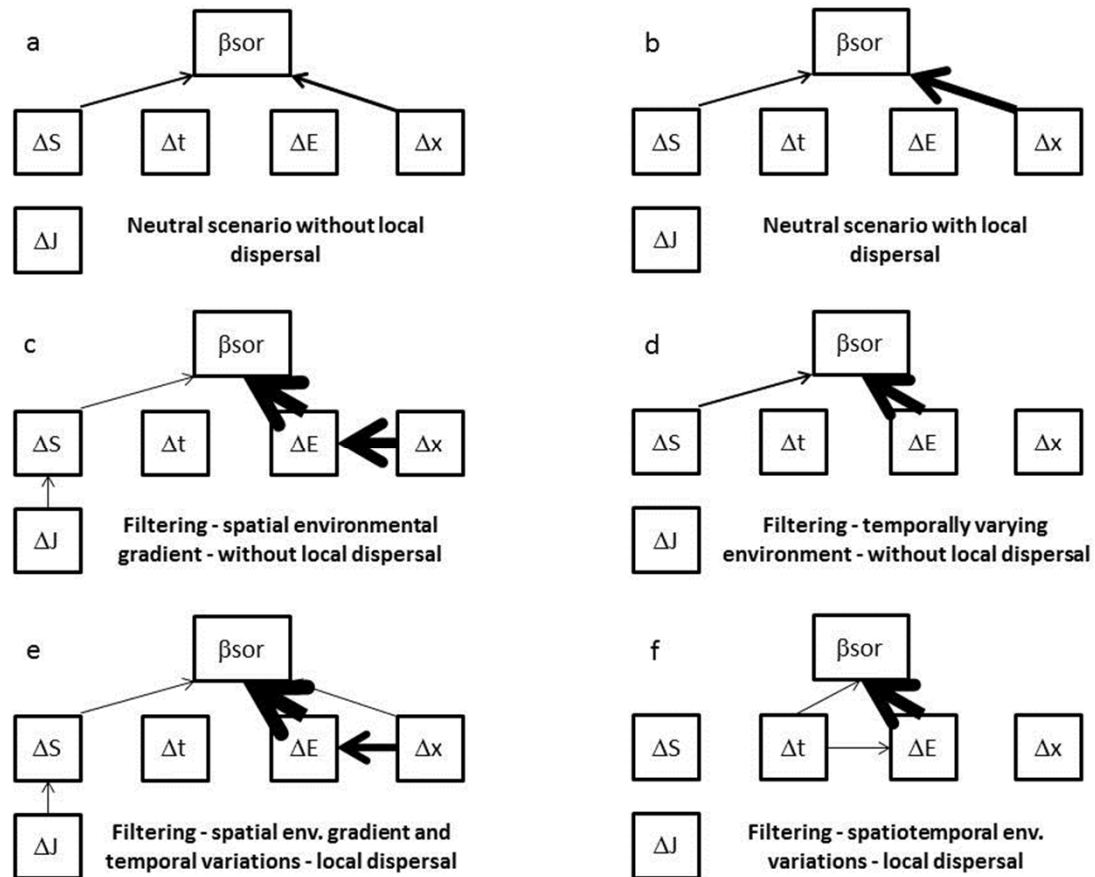
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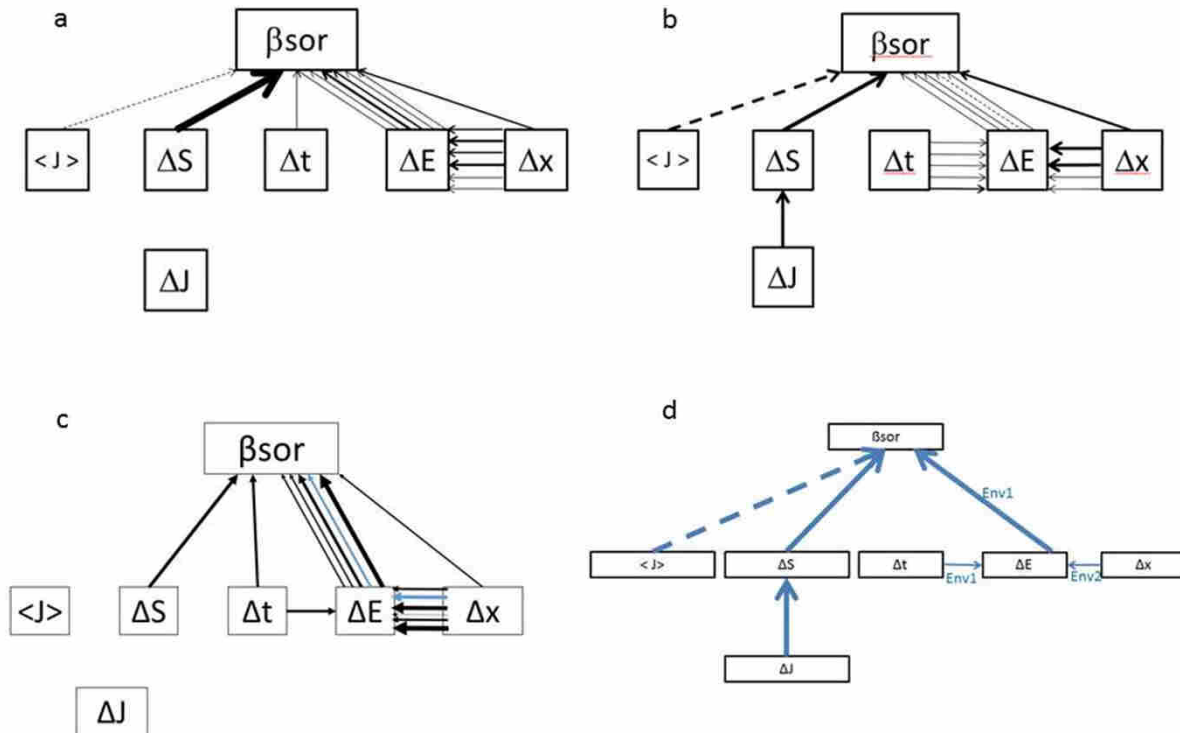
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A dynamical framework for studying metacommunity dynamics



a: freshwater fishes. b: aquatic invertebrates. c: molluscs. d: aquatic plants.

In prep. Joint work with F. Arthaud, S. Blanchet, J. Crabot, T. Datry, P. David, M. Dubart, F. Laroche, F. Massol, F. Munoz

Challenge: understanding the impact of environmental spatiotemporal variability

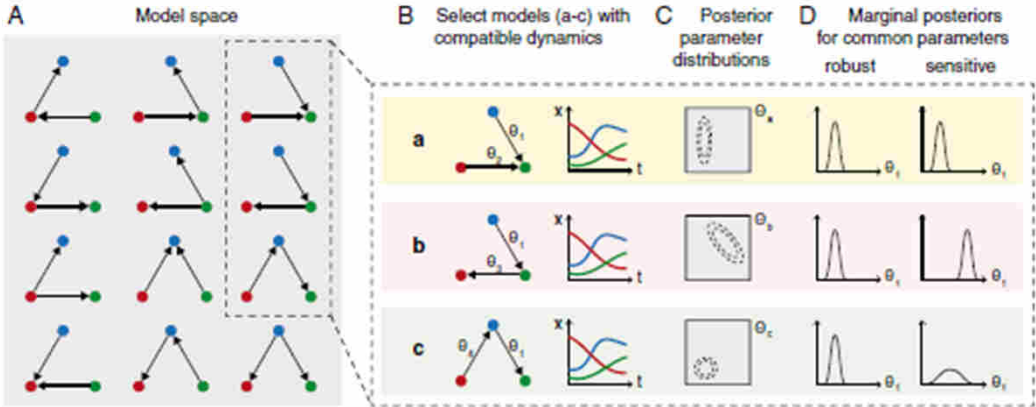
Challenge: understanding the impact of environmental spatiotemporal variability



© Célia Pouget, Co-advisor: Julien Pottier

Challenges for modelling

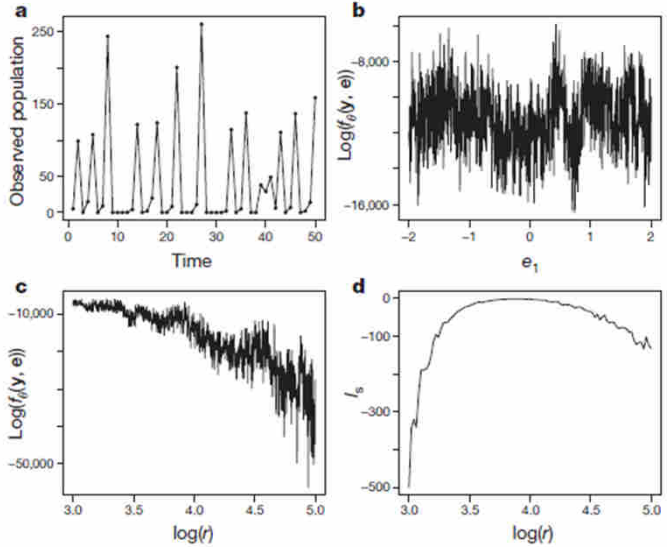
- Structural sensitivity analysis



Babtie et al. PNAS 2014

- Summarizing temporal trajectories

$$N_{t+1} = rN_t e^{-N_t + \epsilon_t}$$



Wood Nature 2010

Thanks for you attention!

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