Integration of ecological networks in a theoritical stochastic model of biogeography

Kévin Cazelles[12]

CSEE, Saskatoon, 2015/05/22

Nicolas Mouquet[1], David Mouillot[3], Dominique Gravel[2].

[1]ISEM, CNRS UMR 5554, Université Montpellier II
[2]Département de Biologie, Université du Québec à Rimouski
[3]ECOSYM, CNRS-IRD-IFREMER UMR 5119, Université Montpellier II

Biogeography

- Biogeography: description/explanation of species distribution

Biogeography

- Biogeography: description/explanation of species distribution
- $\mathbb{P}(X_1, X_2, ..., X_n) = f(V_1, V_2, ..., V_p)$

Biogeography

- Biogeography: description/explanation of species distribution
- $\mathbb{P}(X_1, X_2, ..., X_n) = f(V_1, V_2, ..., V_p)$
- $V_1, V_2, ..., V_p \quad \Rightarrow$ typically abiotic factors

Biogeography

- Biogeography: description/explanation of species distribution
- $\mathbb{P}(X_1, X_2, ..., X_n) = f(V_1, V_2, ..., V_p)$
- $V_1, V_2, ..., V_p \quad \Rightarrow$ typically abiotic factors
- Grinnelian niche and Species Distribution Models (SDM)

Biogeography

- Biogeography: description/explanation of species distribution
- $\mathbb{P}(X_1, X_2, ..., X_n) = f(V_1, V_2, ..., V_p)$
- $V_1, V_2, ..., V_p \quad \Rightarrow$ typically abiotic factors
- Grinnelian niche and Species Distribution Models (SDM)
- However in 1998, in Nature ...

Making mistakes when predicting shifts in species range in response to global warming

Andrew J. Davis*, Linda S. Jenkinson*, John H. Lawton†, Bryan Shorrocks* & Simon Wood†‡

Biogeography and interactions

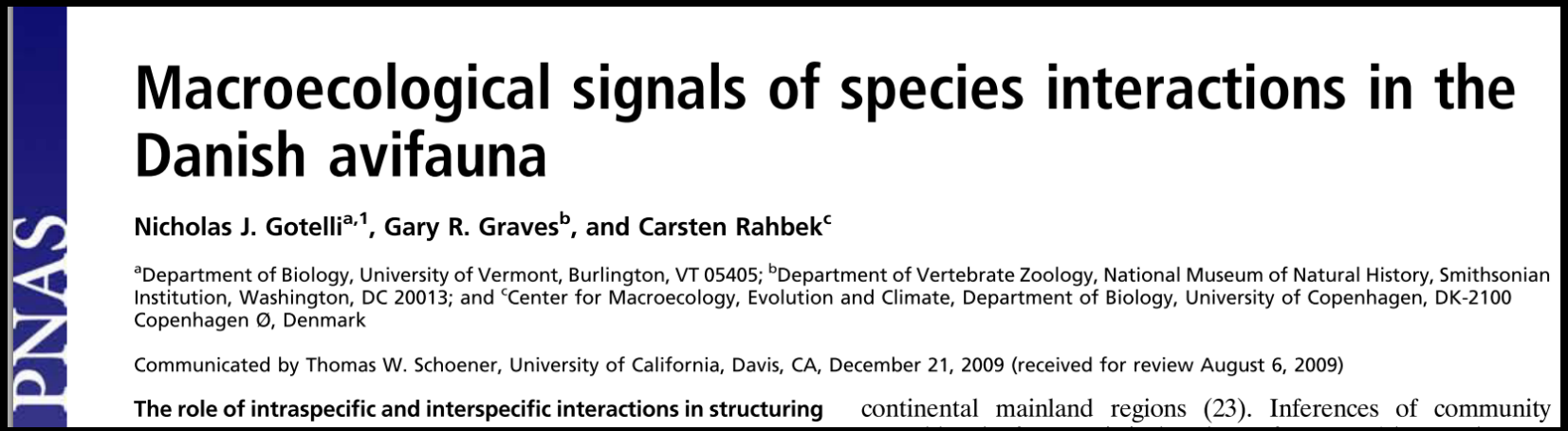
- Assumption: ecological interactions do not matter at large spatial scales

Biogeography and interactions

- Assumption: ecological interactions do not matter at large spatial scales
- Recent studies show their importance, *e.g.* in December 2009

Biogeography and interactions

- Assumption: ecological interactions do not matter at large spatial scales
- Recent studies show their importance, *e.g.* in December 2009



PNAS

Macroecological signals of species interactions in the Danish avifauna

Nicholas J. Gotelli[a,1], Gary R. Graves[b], and Carsten Rahbek[c]

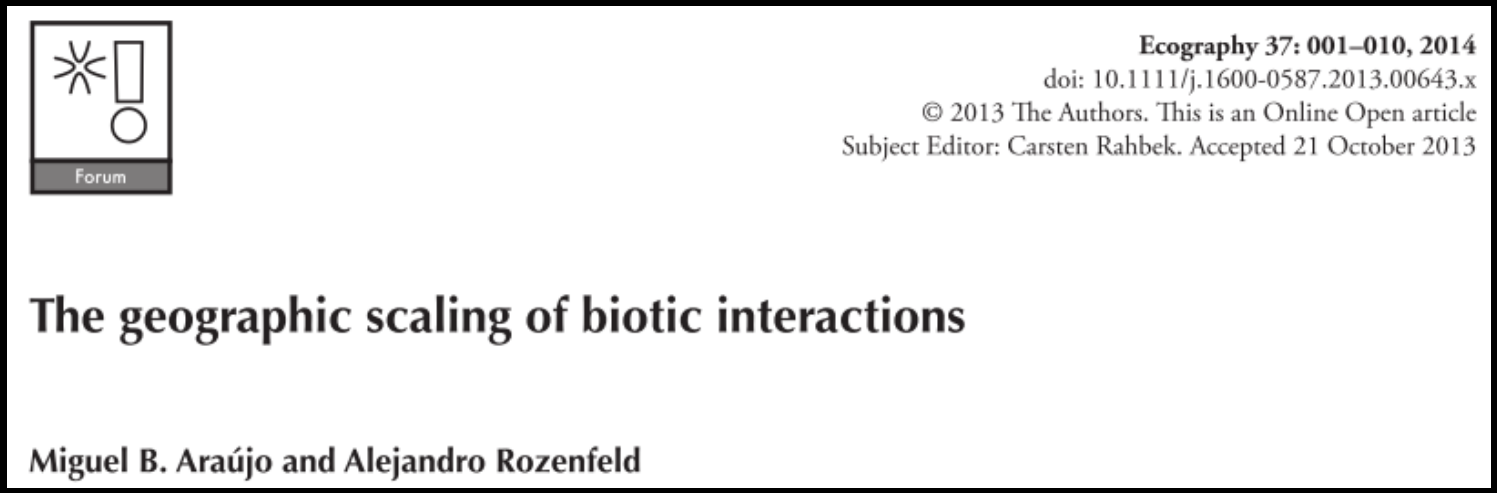
[a]Department of Biology, University of Vermont, Burlington, VT 05405; [b]Department of Vertebrate Zoology, National Museum of Natural History, Smithsonian Institution, Washington, DC 20013; and [c]Center for Macroecology, Evolution and Climate, Department of Biology, University of Copenhagen, DK-2100 Copenhagen Ø, Denmark

Communicated by Thomas W. Schoener, University of California, Davis, CA, December 21, 2009 (received for review August 6, 2009)

The role of intraspecific and interspecific interactions in structuring continental mainland regions (23). Inferences of community

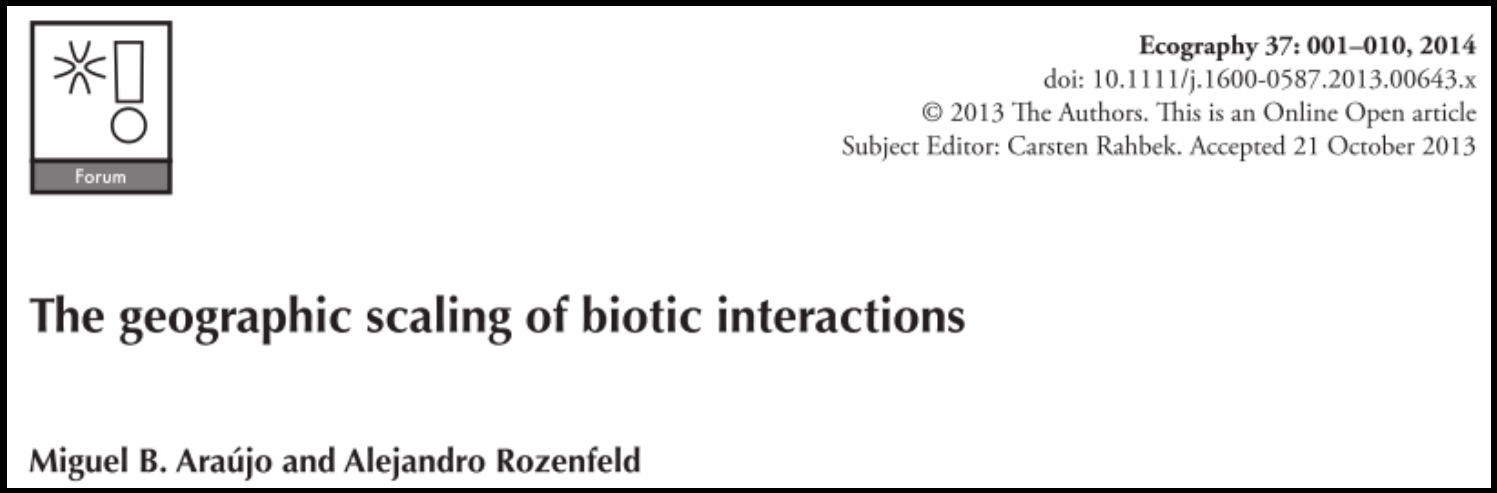
Interactions, a matter a scale ?

- Fundamental questions:
  How interaction consequences propagate over spatial scales ?



Interactions, a matter a scale ?

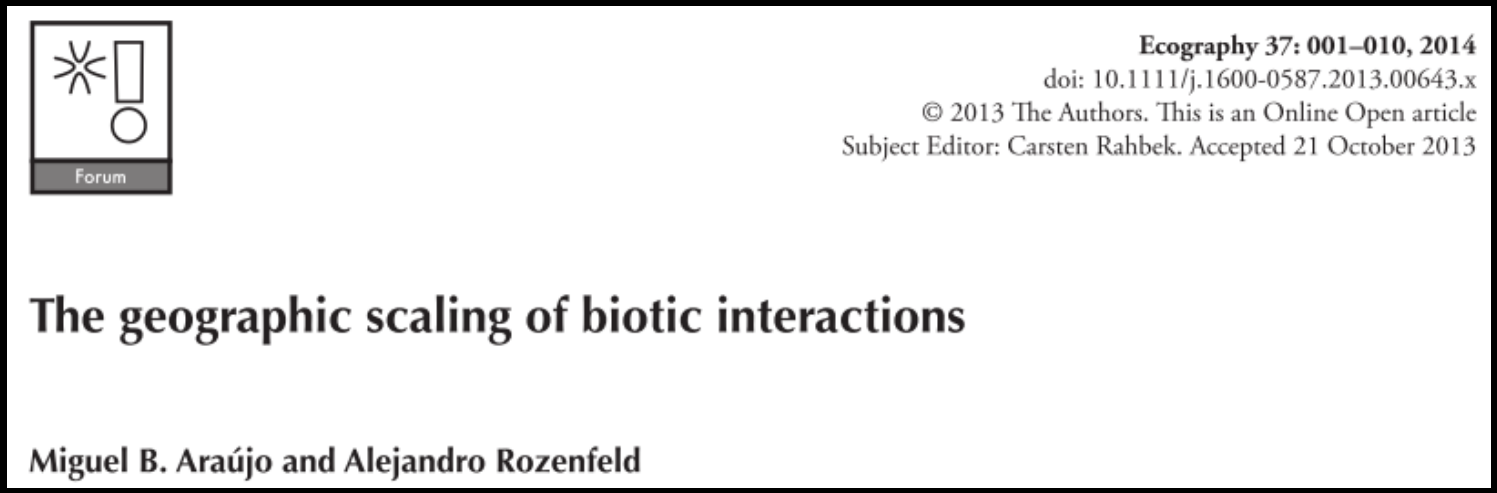
- Fundamental questions:
  How interaction consequences propagate over spatial scales ?



What does a co-occurrence mean ?

Interactions, a matter a scale ?

- Fundamental questions:
  How interaction consequences propagate over spatial scales ?



  What does a co-occurrence mean ?

- The Theory of Biogeography may require some changes !

Variables of interest

1. **Movement**: dispersal capacities of species, ϕ

Variables of interest

1. **Movement**: dispersal capacities of species, ϕ
2. **Abiotic variables**: temperature, precipitation,... λ

Variables of interest

1. **Movement**: dispersal capacities of species, ϕ
2. **Abiotic variables**: temperature, precipitation,... λ
3. **Biotic variables**: interaction networks, depicted by community matrix B

Variables of interest

1. **Movement**: dispersal capacities of species, ϕ
2. **Abiotic variables**: temperature, precipitation,... λ
3. **Biotic variables**: interaction networks, depicted by community matrix B
4. **Evolution**: changes in species characteristics over time, τ

Variables of interest

1. **Movement**: dispersal capacities of species, ϕ
2. **Abiotic variables**: temperature, precipitation,... λ
3. **Biotic variables**: interaction networks, depicted by community matrix B
4. **Evolution**: changes in species characteristics over time, τ

- For a given locality, we search for:

$$\mathbb{P}(X_1, X_2, ..., X_n) = f(\phi, \lambda, B, \tau)$$

Variables of interest

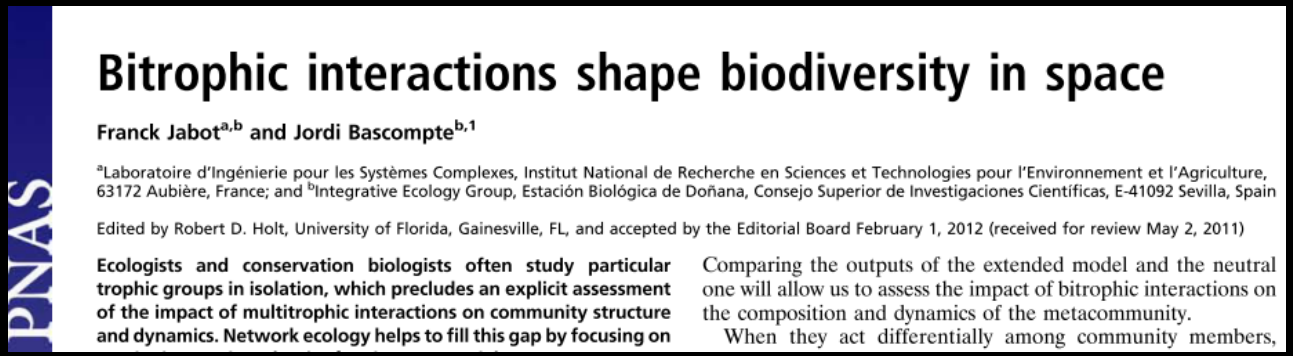
1. **Movement**: dispersal capacities of species, ϕ
2. **Abiotic variables**: temperature, precipitation,... λ
3. **Biotic variables**: interaction networks, depicted by community matrix B
4. **Evolution**: changes in species characteristics over time, τ

- For a given locality, we search for:

$$\mathbb{P}(X_1, X_2, ..., X_n) = f(\phi, \lambda, B, \tau)$$

Theoretical development

- Recent attempt for integrating a subset of the above mentioned variables:



PNAS

Bitrophic interactions shape biodiversity in space

Franck Jabot[a,b] and Jordi Bascompte[b,1]

[a]Laboratoire d'Ingénierie pour les Systèmes Complexes, Institut National de Recherche en Sciences et Technologies pour l'Environnement et l'Agriculture, 63172 Aubière, France; and [b]Integrative Ecology Group, Estación Biológica de Doñana, Consejo Superior de Investigaciones Científicas, E-41092 Sevilla, Spain

Edited by Robert D. Holt, University of Florida, Gainesville, FL, and accepted by the Editorial Board February 1, 2012 (received for review May 2, 2011)

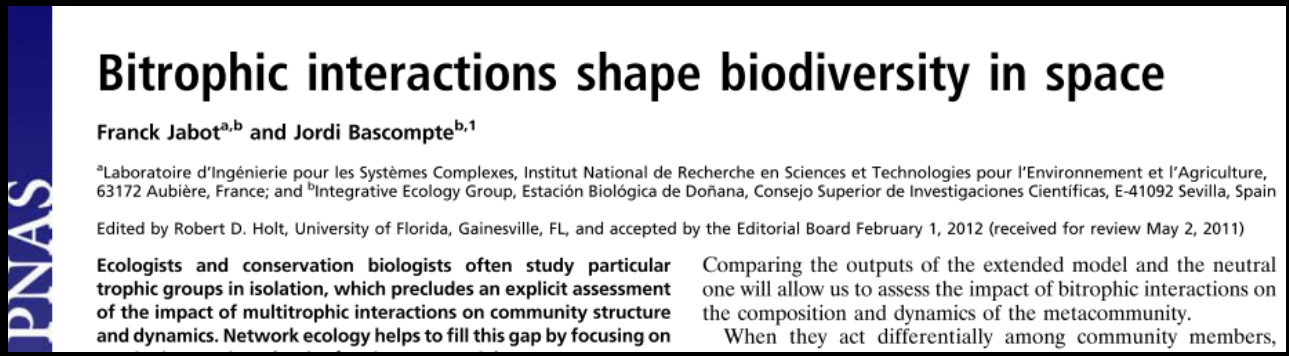
Ecologists and conservation biologists often study particular trophic groups in isolation, which precludes an explicit assessment of the impact of multitrophic interactions on community structure and dynamics. Network ecology helps to fill this gap by focusing on

Comparing the outputs of the extended model and the neutral one will allow us to assess the impact of bitrophic interactions on the composition and dynamics of the metacommunity.

When they act differentially among community members,

Theoretical development

- Recent attempt for integrating a subset of the above mentioned variables:



PNAS

Bitrophic interactions shape biodiversity in space

Franck Jabot[a,b] and Jordi Bascompte[b,1]

[a]Laboratoire d'Ingénierie pour les Systèmes Complexes, Institut National de Recherche en Sciences et Technologies pour l'Environnement et l'Agriculture, 63172 Aubière, France; and [b]Integrative Ecology Group, Estación Biológica de Doñana, Consejo Superior de Investigaciones Científicas, E-41092 Sevilla, Spain

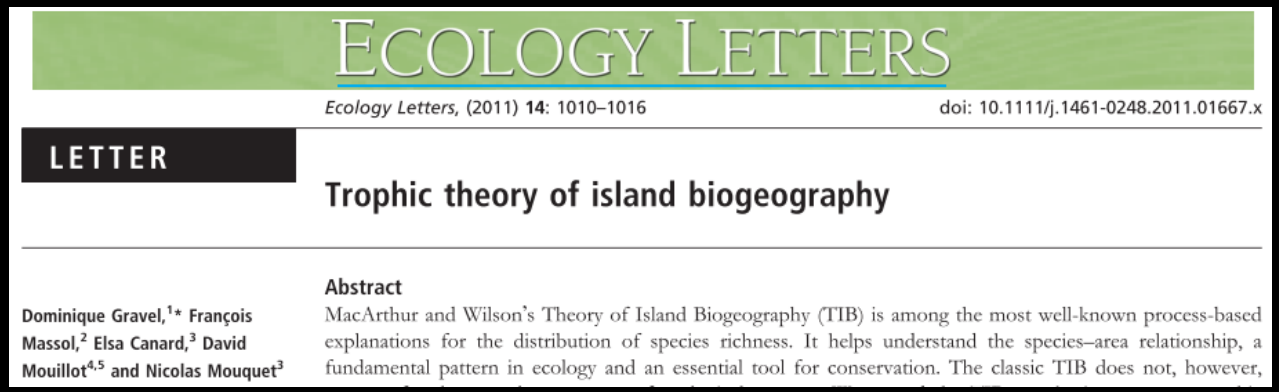
Edited by Robert D. Holt, University of Florida, Gainesville, FL, and accepted by the Editorial Board February 1, 2012 (received for review May 2, 2011)

Ecologists and conservation biologists often study particular trophic groups in isolation, which precludes an explicit assessment of the impact of multitrophic interactions on community structure and dynamics. Network ecology helps to fill this gap by focusing on

Comparing the outputs of the extended model and the neutral one will allow us to assess the impact of bitrophic interactions on the composition and dynamics of the metacommunity.

When they act differentially among community members,

- Trophic extension of the Theory of Island Biogeography (TTIB):



ECOLOGY LETTERS

Ecology Letters, (2011) **14**: 1010–1016 doi: 10.1111/j.1461-0248.2011.01667.x

LETTER

Trophic theory of island biogeography

Dominique Gravel,[1]* François Massol,[2] Elsa Canard,[3] David Mouillot[4,5] and Nicolas Mouquet[3]

Abstract

MacArthur and Wilson's Theory of Island Biogeography (TIB) is among the most well-known process-based explanations for the distribution of species richness. It helps understand the species–area relationship, a fundamental pattern in ecology and an essential tool for conservation. The classic TIB does not, however,

Our Aim

- Supporting the development of the theory of Biogeography

Our Aim

- Supporting the development of the theory of Biogeography
- Generalizing the TTIB model to any kind of networks

Our Aim

- Supporting the development of the theory of Biogeography
- Generalizing the TTIB model to any kind of networks
- Adding environmental gradients

Theory of Island Biogeography (1967)

1. The theory of MacArthur and Wilson is often summarized as follows:

$$\frac{dS}{dt} = c(P - S) - eS$$

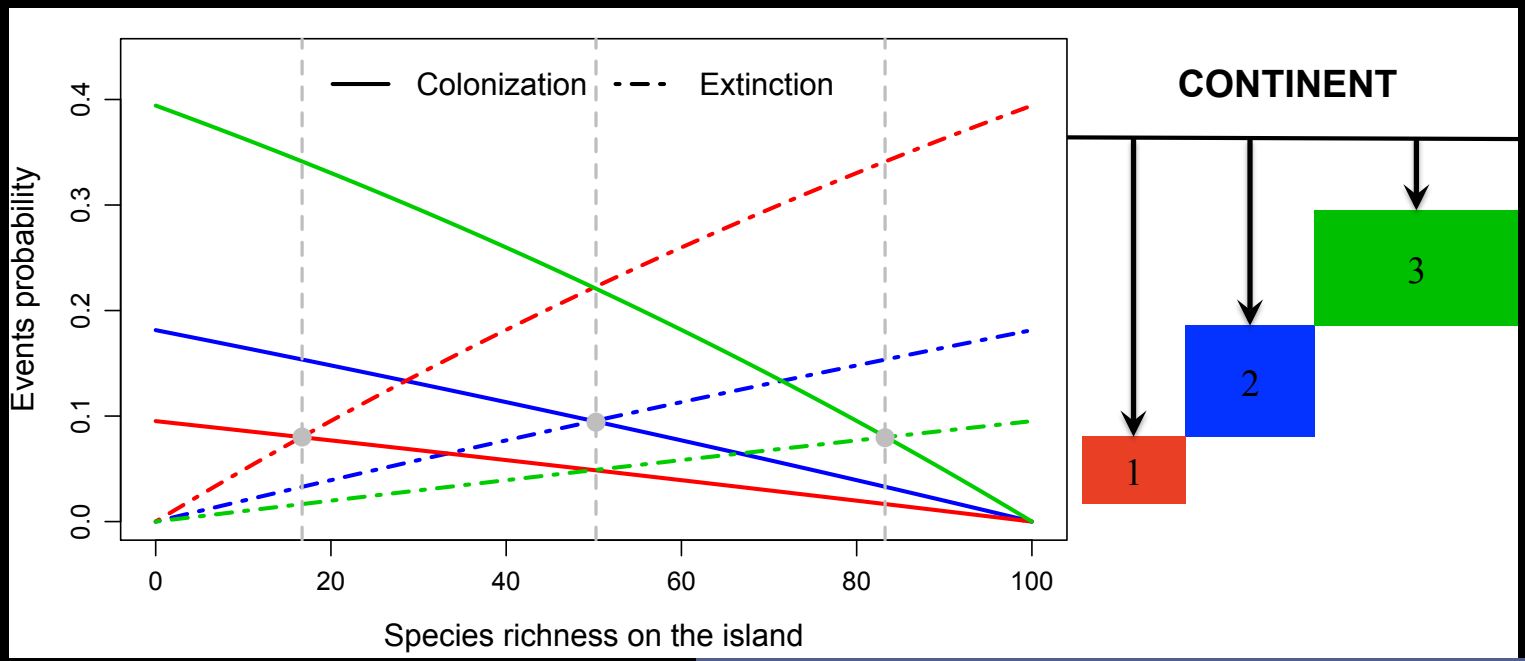
Theory of Island Biogeography (1967)

1. The theory of MacArthur and Wilson is often summarized as follows:

$$\frac{dS}{dt} = c(P - S) - eS$$

2. Equilibrium reached for:

$$S_{eq} = P\frac{c}{c + e}$$



The challenge of adding interactions

- We integrate B into the classical model.

The challenge of adding interactions

- We integrate B into the classical model.

- Let us consider 2 species 1 and 2
- Presence on the island: $X_t = (X_{1,t}, X_{2,t})$
- 4 possible states for X_t:
  $S_1 = (1,1),\ S_2 = (1,0),\ S_3 = (0,1),\ S_4 = (0,0)$

The challenge of adding interactions

- We integrate B into the classical model.

- Let us consider 2 species 1 and 2
- Presence on the island: $X_t = (X_{1,t}, X_{2,t})$
- 4 possible states for X_t:
  $S_1 = (1,1),\ S_2 = (1,0),\ S_3 = (0,1),\ S_4 = (0,0)$

- How to switch from X_t to X_{t+dt} ?
- Markov chain !

Transition Matrix of the Markov Chains

For independent species:

	$(X_{1,t+dt}, X_{2,t+dt})$			
$(X_{1,t}, X_{2,t})$	$(1,1)$	$(1,0)$	$(0,1)$	$(0,0)$
$(1,1)$	$(1-e_1dt)(1-e_2dt)$	$(1-e_1dt)e_2dt$	$e_1dt(1-e_2dt)$	e_1dte_2dt
$(1,0)$	$(1-e_1dt)c_2dt$	$(1-e_1dt)(1-c_2dt)$	e_1dtc_2dt	$e_1dt(1-c_2dt)$
$(0,1)$	$c_1dt(1-e_2dt)$	c_1dte_2dt	$(1-c_1dt)(1-e_2dt)$	$(1-c_1dt)e_2dt$
$(0,0)$	c_1dtc_2dt	$c_1dt(1-c_2dt)$	$(1-c_1dt)c_2dt$	$(1-c_1dt)(1-c_2dt)$

Transition Matrix of the Markov Chains

For independent species:

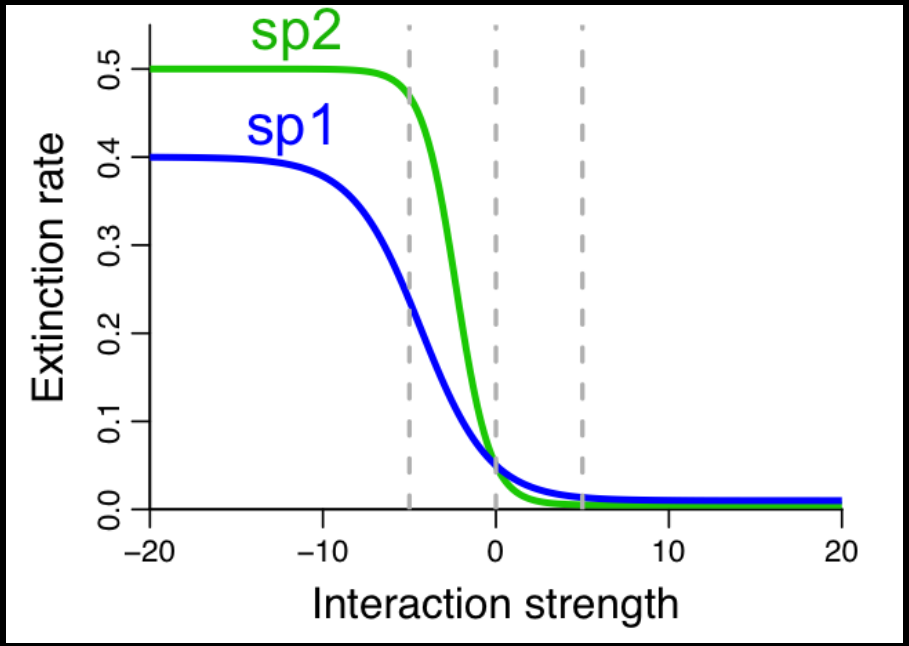
	$(X_{1,t+dt}, X_{2,t+dt})$			
$(X_{1,t}, X_{2,t})$	$(1,1)$	$(1,0)$	$(0,1)$	$(0,0)$
$(1,1)$	$(1-e_1dt)(1-e_2dt)$	$(1-e_1dt)e_2dt$	$e_1dt(1-e_2dt)$	e_1dte_2dt
$(1,0)$	$(1-e_1dt)c_2dt$	$(1-e_1dt)(1-c_2dt)$	e_1dtc_2dt	$e_1dt(1-c_2dt)$
$(0,1)$	$c_1dt(1-e_2dt)$	c_1dte_2dt	$(1-c_1dt)(1-e_2dt)$	$(1-c_1dt)e_2dt$
$(0,0)$	c_1dtc_2dt	$c_1dt(1-c_2dt)$	$(1-c_1dt)c_2dt$	$(1-c_1dt)(1-c_2dt)$

- Generally applicable to n species.
- Probabilities of all communities at the equilibrium.

Transition Matrix of the Markov Chains

- How interactions impact presence probabilities ?

$$(\text{Interaction Strength})_t = BX_t$$



- Without interaction, we get the classical model.

Simulations

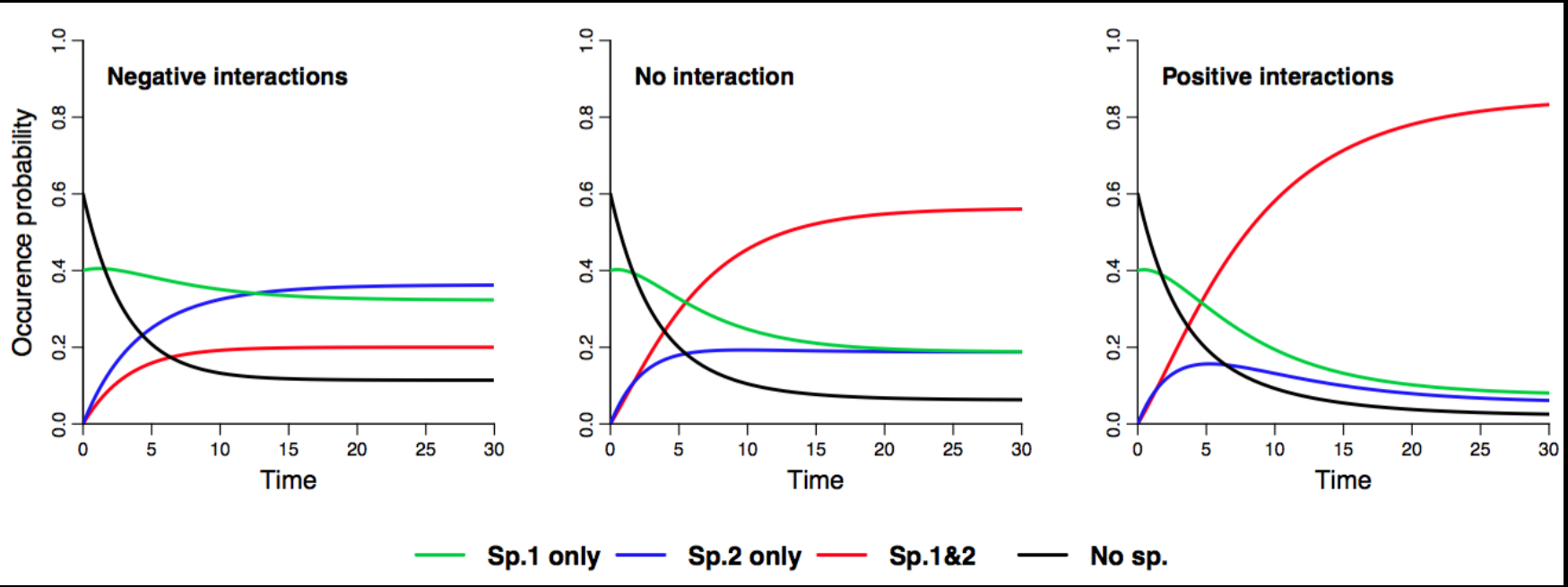
Given:

- ecological network

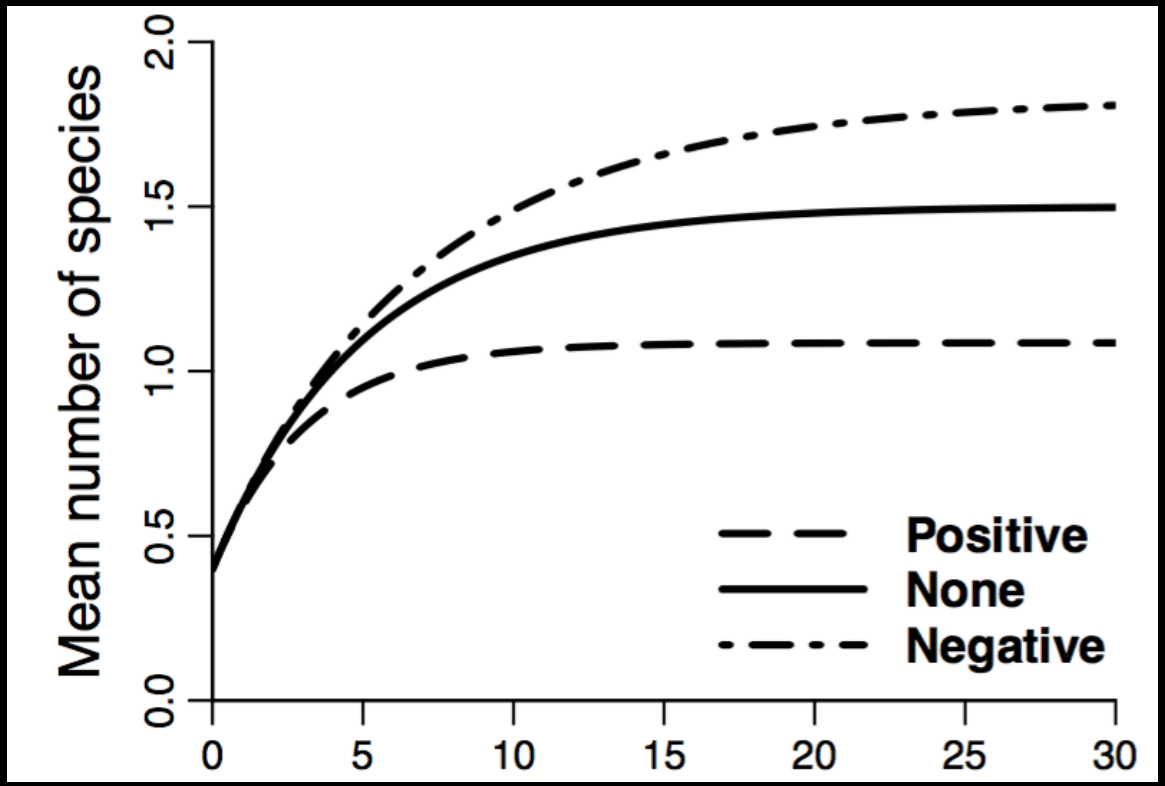
We get:

- Presence probabilities of all communities at equilibrium
- Any probability defined as a sum of the latter, *e.g.* the presence probability of any species

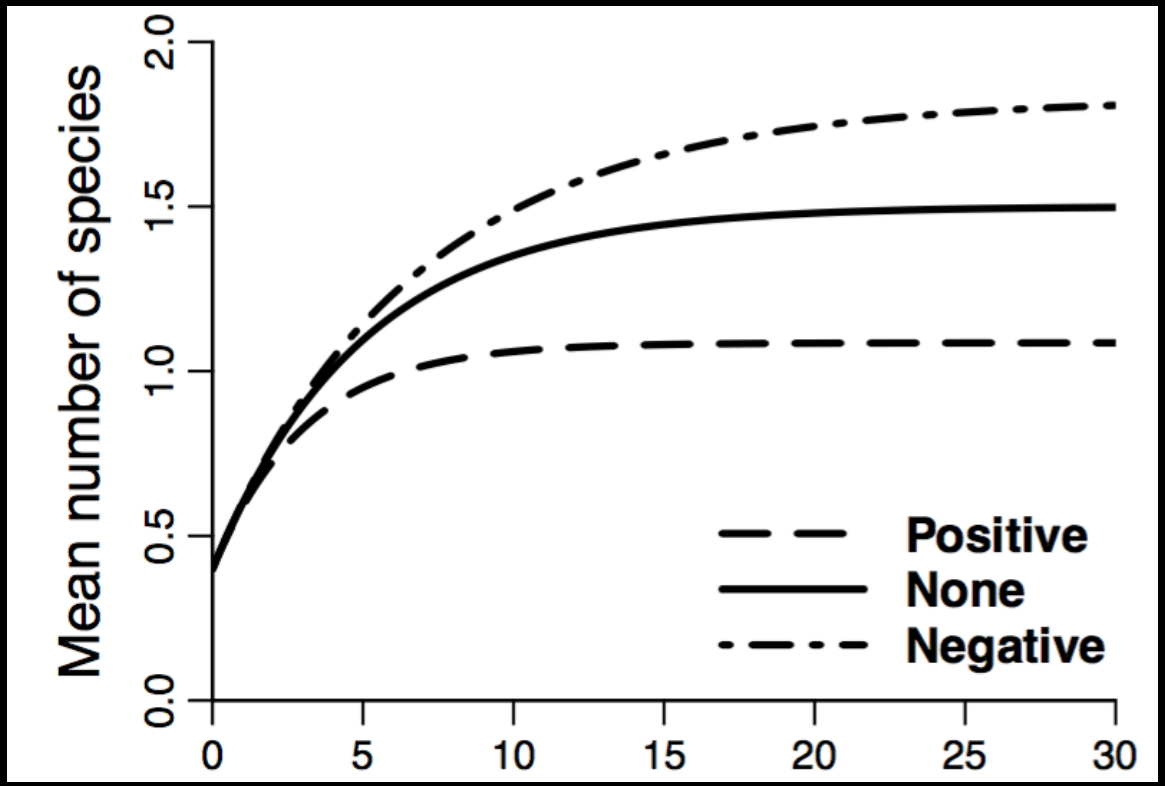
Example with two species



Example with two species



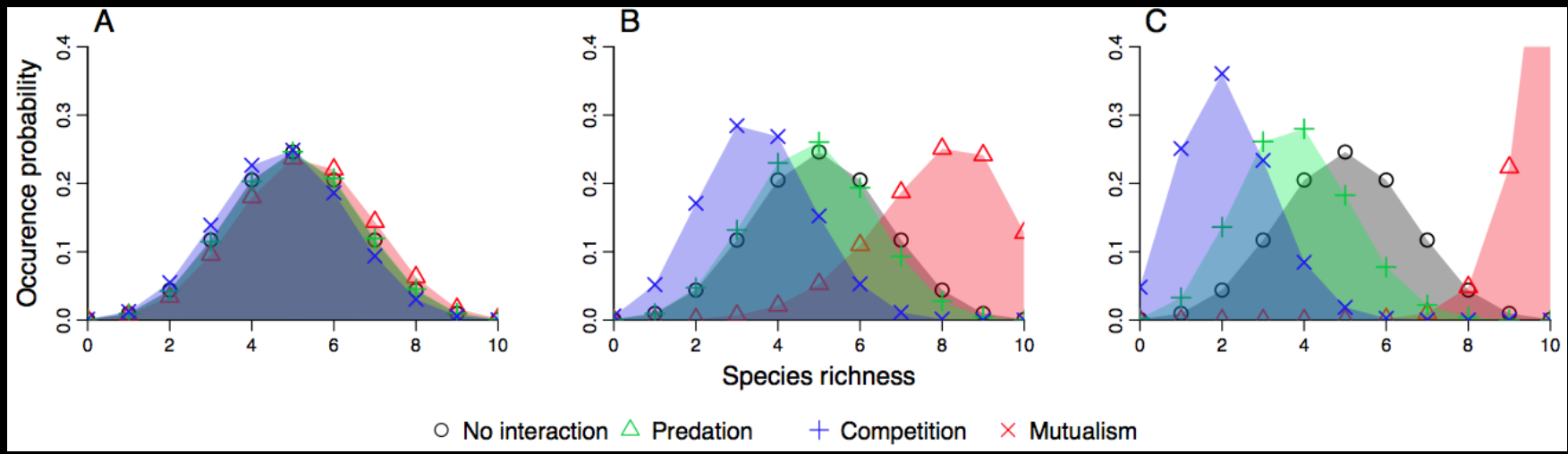
Example with two species



Exploration for networks of 10 species (niche model).

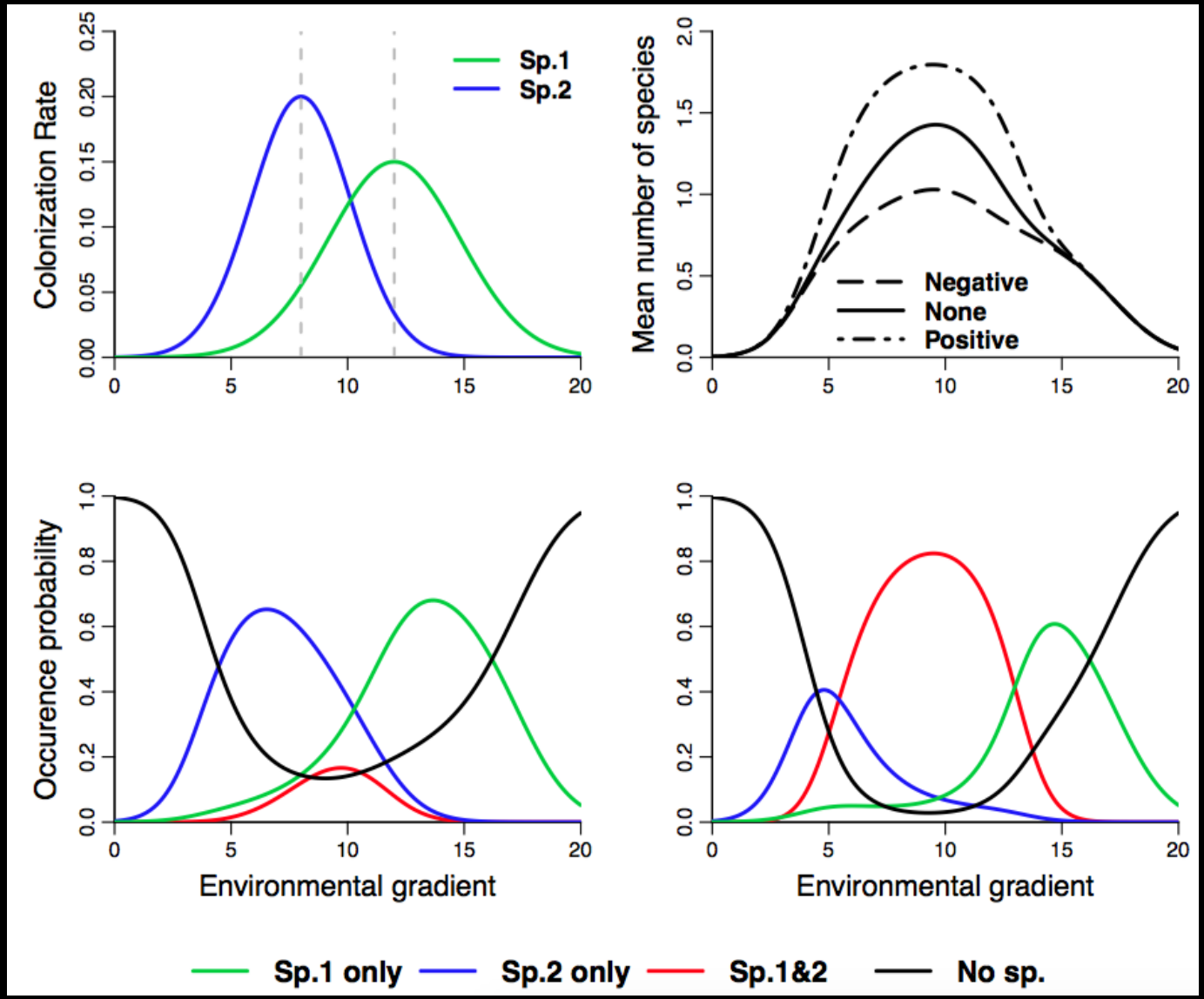
Presence probability of communities of a given diversity

$$\mathbb{P}(S_{eq} = n) = \sum_{i \mid |S_i|^2 = n} \mathbb{P}(X_{eq} = S_i)$$

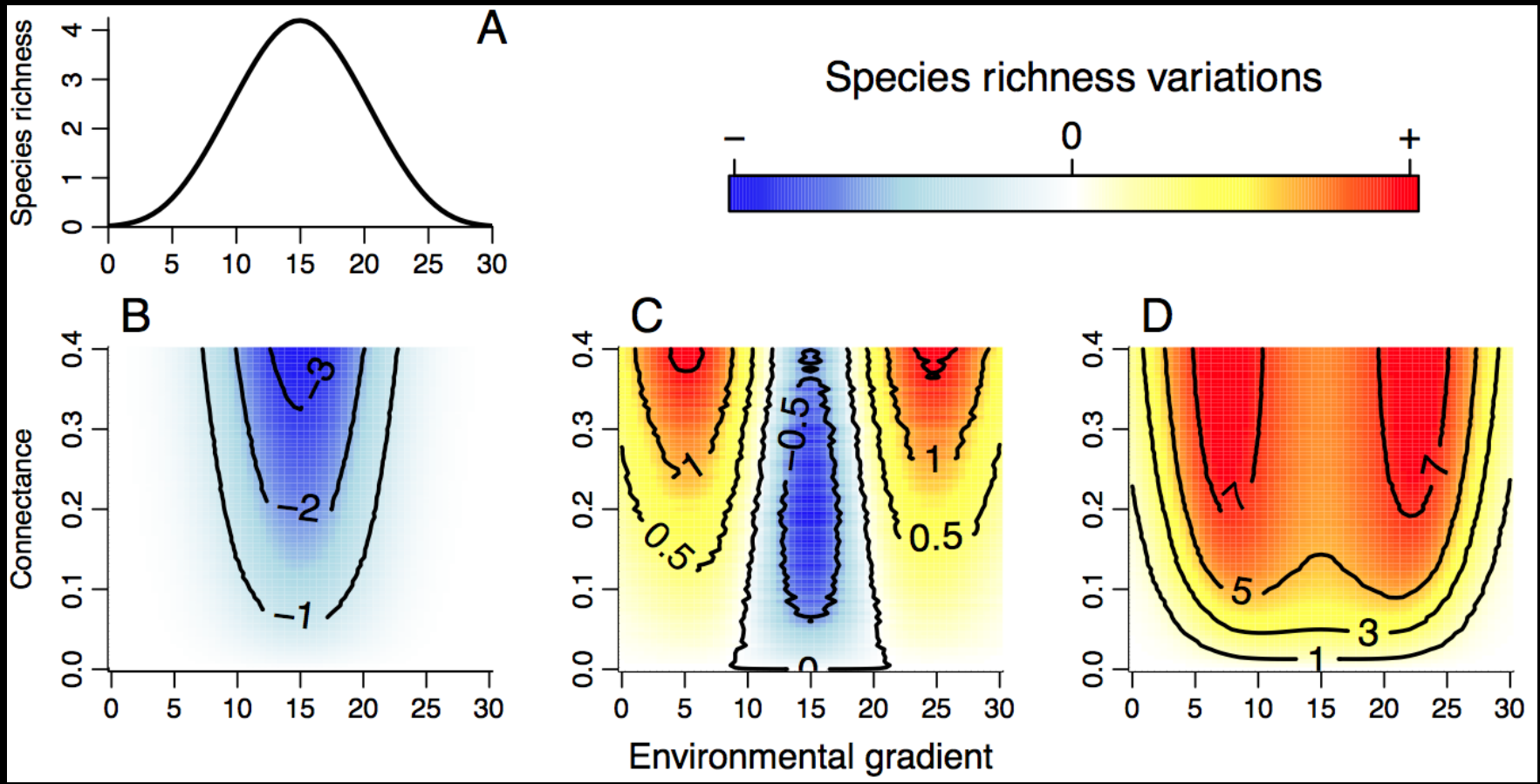


From A to C we increase the interaction strengths.

Environmental gradient + interaction



Environmental gradient + interaction



Towards applications ?

- Large transition matrix: $2^n \times 2^n$

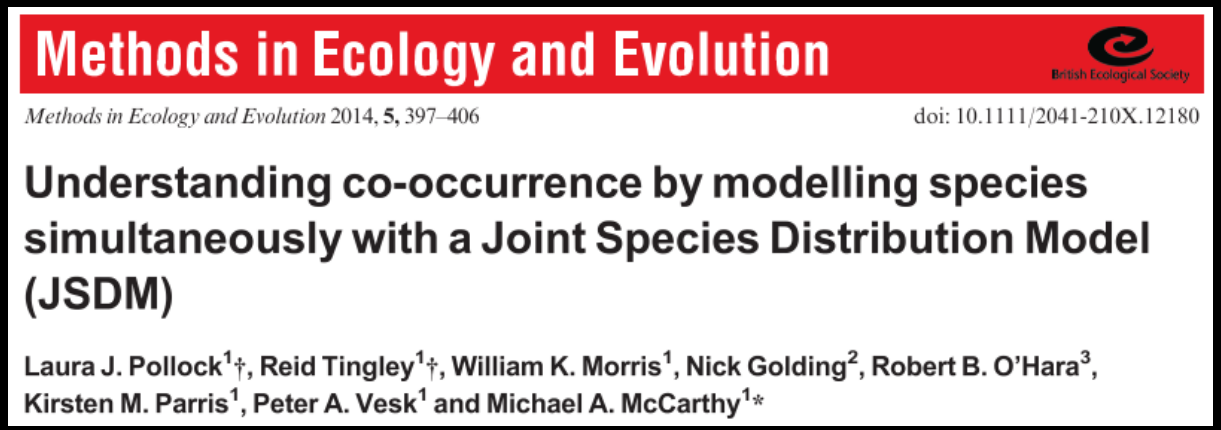
Towards applications ?

- Large transition matrix: $2^n \times 2^n$
- How to fit data ? Using set of species ? Species correlation ?

Towards applications ?

- Large transition matrix: $2^n \times 2^n$
- How to fit data ? Using set of species ? Species correlation ?

- Theoretical foundations for emerging approaches:



Methods in Ecology and Evolution

British Ecological Society

Methods in Ecology and Evolution 2014, **5**, 397–406 doi: 10.1111/2041-210X.12180

Understanding co-occurrence by modelling species simultaneously with a Joint Species Distribution Model (JSDM)

Laura J. Pollock[1]†, Reid Tingley[1]†, William K. Morris[1], Nick Golding[2], Robert B. O'Hara[3], Kirsten M. Parris[1], Peter A. Vesk[1] and Michael A. McCarthy[1]*

Towards applications ?

Many questions remain unanswered:

- How the interaction propagate over spatial scales ?

Towards applications ?

Many questions remain unanswered:

- How the interaction propagate over spatial scales ?
- What the meaning of matrix B at large scale ?

Towards applications ?

Many questions remain unanswered:

- How the interaction propagate over spatial scales ?
- What the meaning of matrix B at large scale ?
- Is there a way to scale $B(\sigma)$?

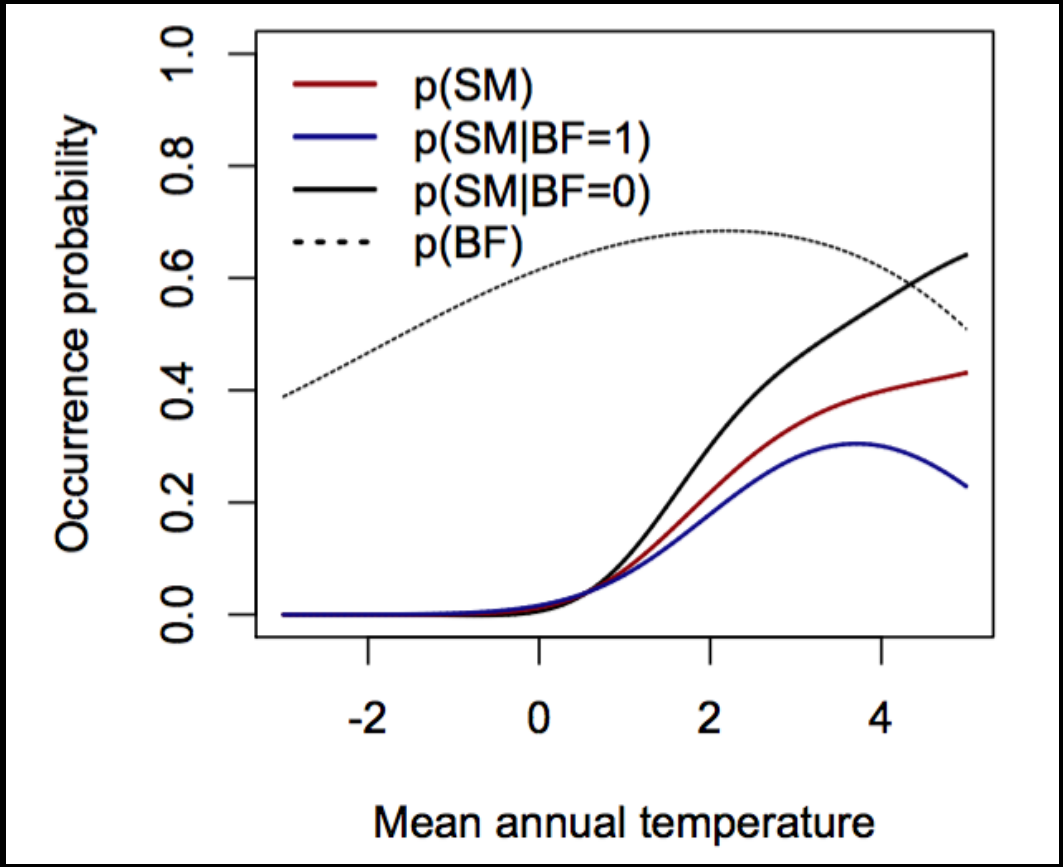
Towards applications ?

Many questions remain unanswered:

- How the interaction propagate over spatial scales ?
- What the meaning of matrix B at large scale ?
- Is there a way to scale $B(\sigma)$?
- Are correlations sufficient to capture "signals" and conclude ?

Work in progress

- Conditional probabilities of occurrence along environmental gradients



BF = Balsam Fir, SM = Sugar Maple

Are ecosystems concerned?

- The challenge is obviously to go further than two species, but...

Are ecosystems concerned?

- The challenge is obviously to go further than two species, but...