Evolution in metacommunities and the maintenance of diversity

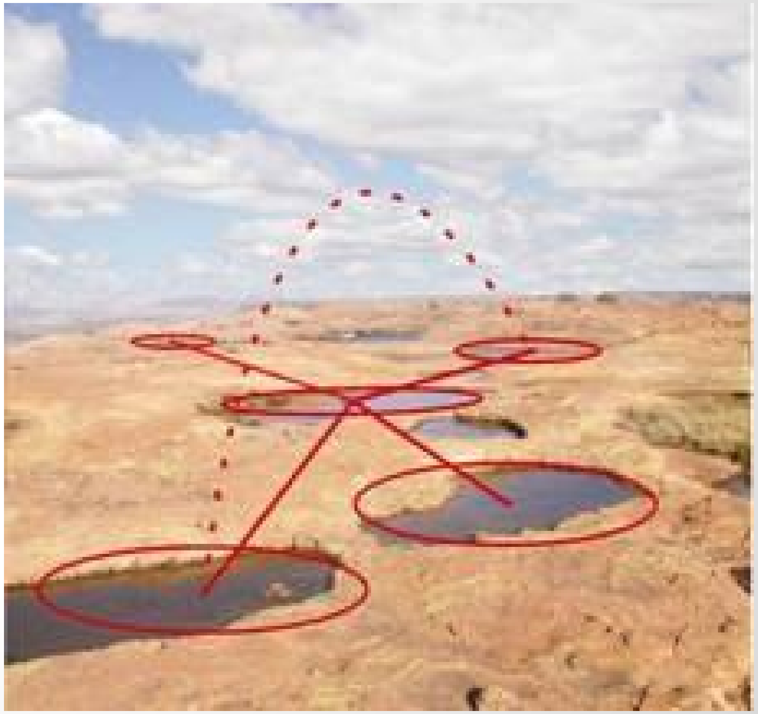
Loeuille & Leibold 2008, American Naturalist
Norberg et al. 2012, Nat Clim Change

What's a metacommunity (Leibold et al. 2004)

- Local, multispecies assemblages

-most often, interactions are considered competitive (else called metawebs)

-dispersal among populations



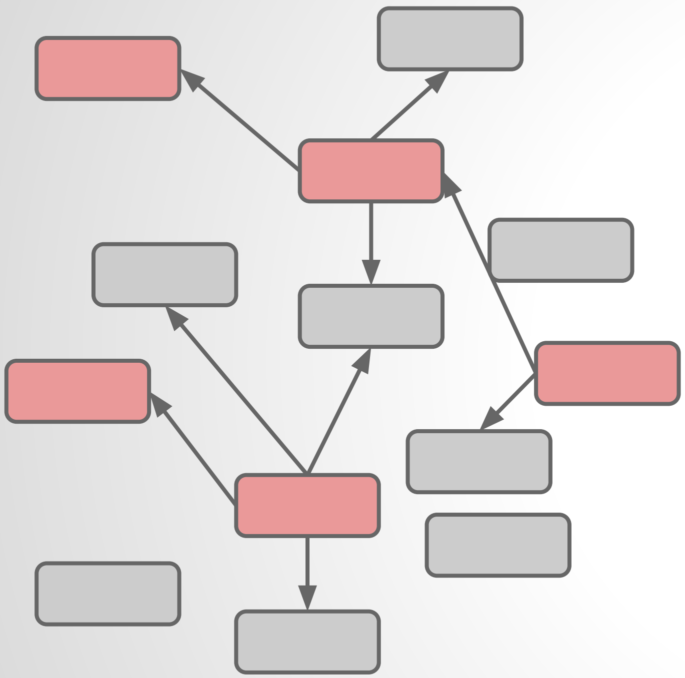
Typical metacommunity questions

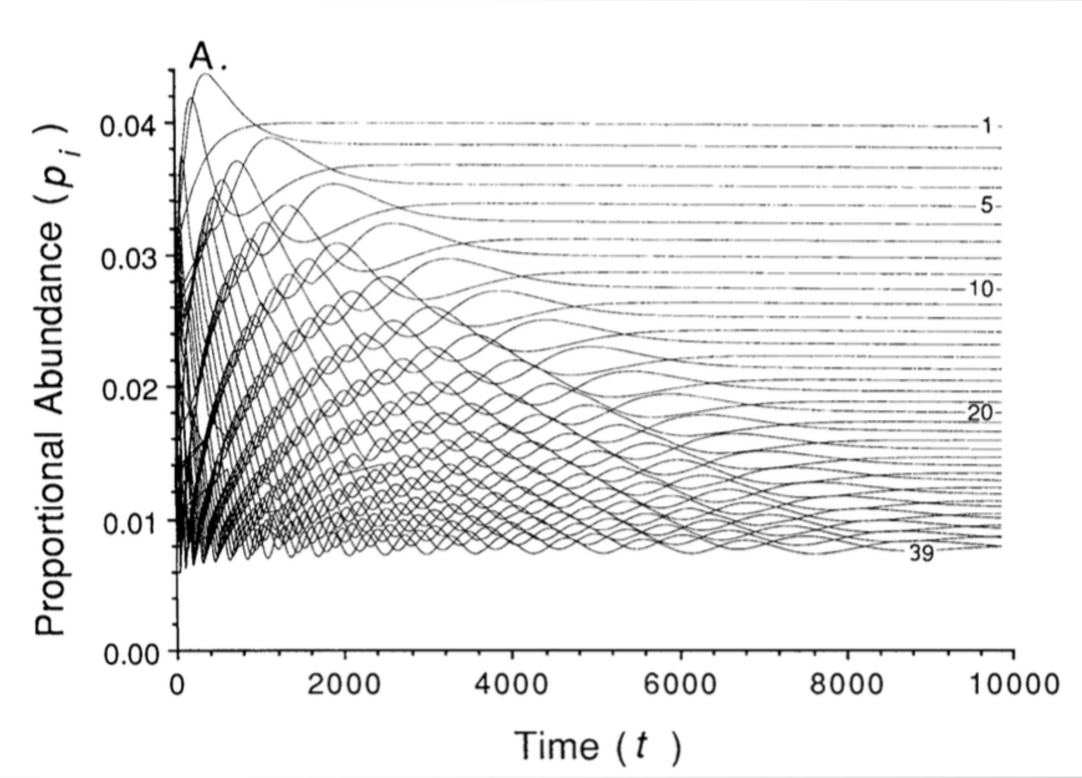
1) What amount of species diversity can I maintain in a single pacth? (α-diversity)
2) What amount of species diversity can I maintain on the whole landscape? (γ-diversity)
3) How is this biodiversity structured (eg, species abundance distribution)
4) What implications for the conservation of species or the management of exploited populations? (eg, creating reserves)

Four different paradigms

1. Patch dynamics (colonization-extinction oriented)
2. Species sorting (niche-based, the most suitable species dominate in a given patch)
3. Mass effects (niche differences and dispersal create source-sink dynamics)
4. Neutral metacommunity (all species equivalent, stochastic mortality, natality, dispersal and speciation) Hubbell 2001.

Example paradigm (Tilman 1994) Competition-colonization TO



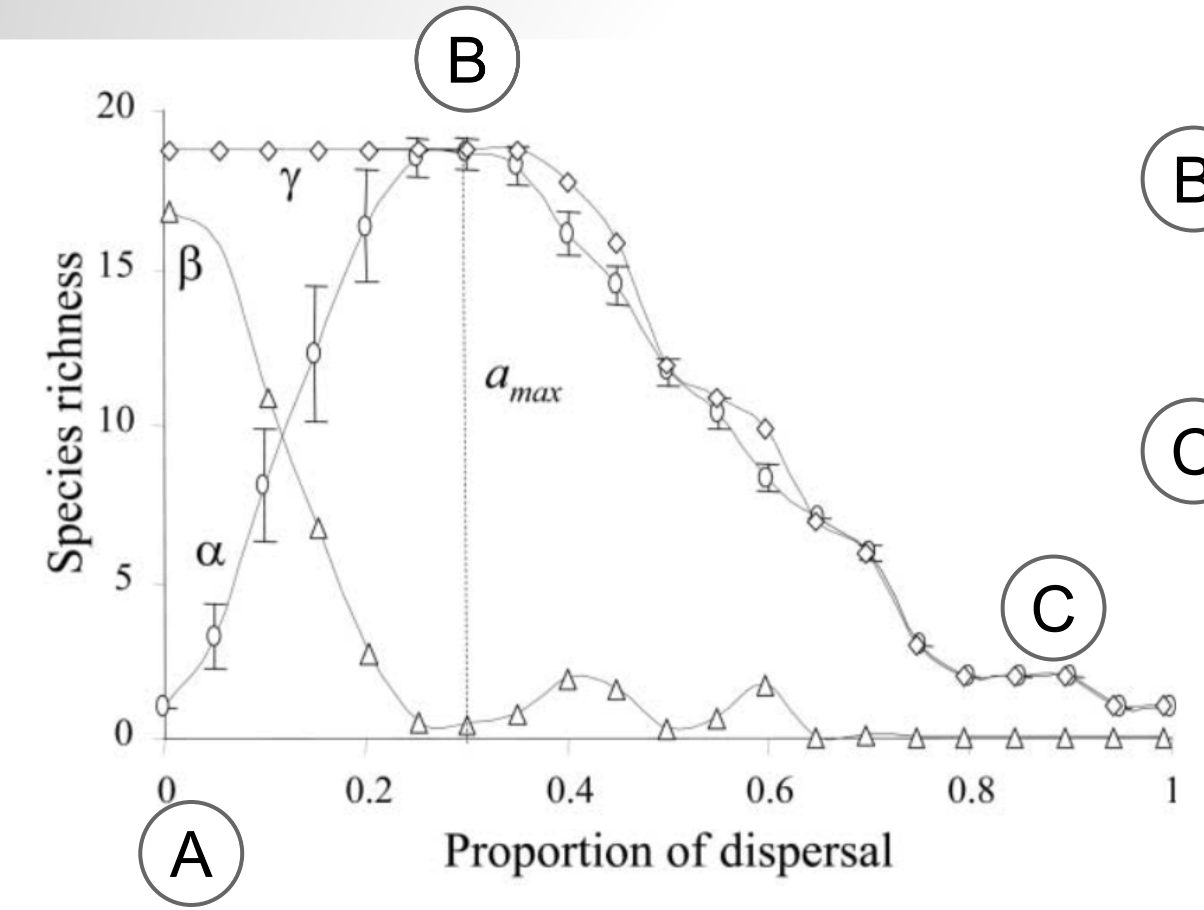


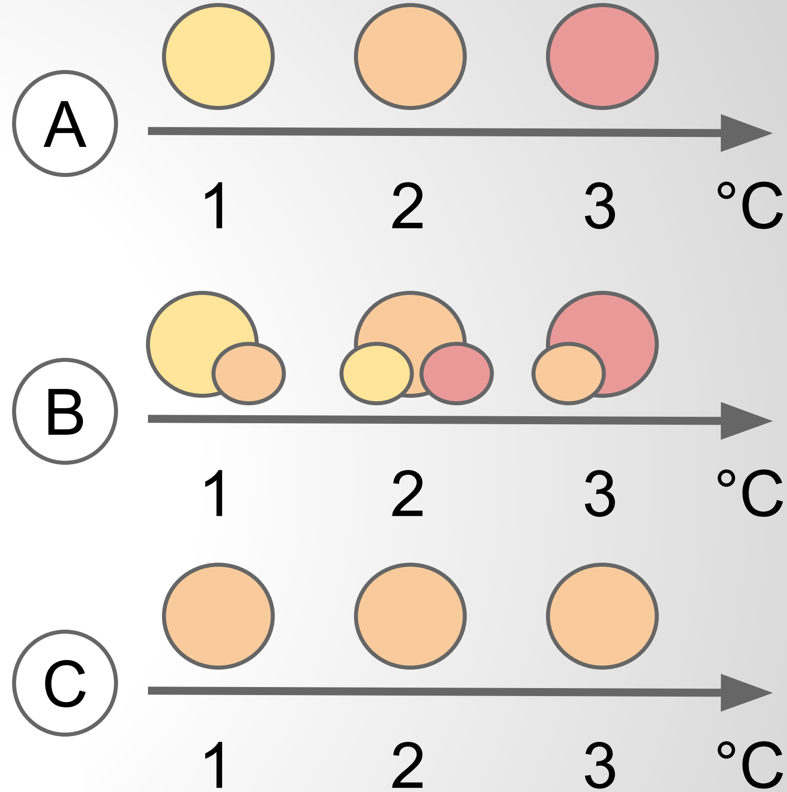
$$\frac{dp_1}{dt} = c_1 p_1(1 - p_1) - m_1 p_1$$

$$c_2 > c_1\left(\frac{\hat{p}_1}{1 - \hat{p}_1} + \frac{m_2}{m_1}\right).$$

Paradigms 2 & 3: Species sorting and mass effects

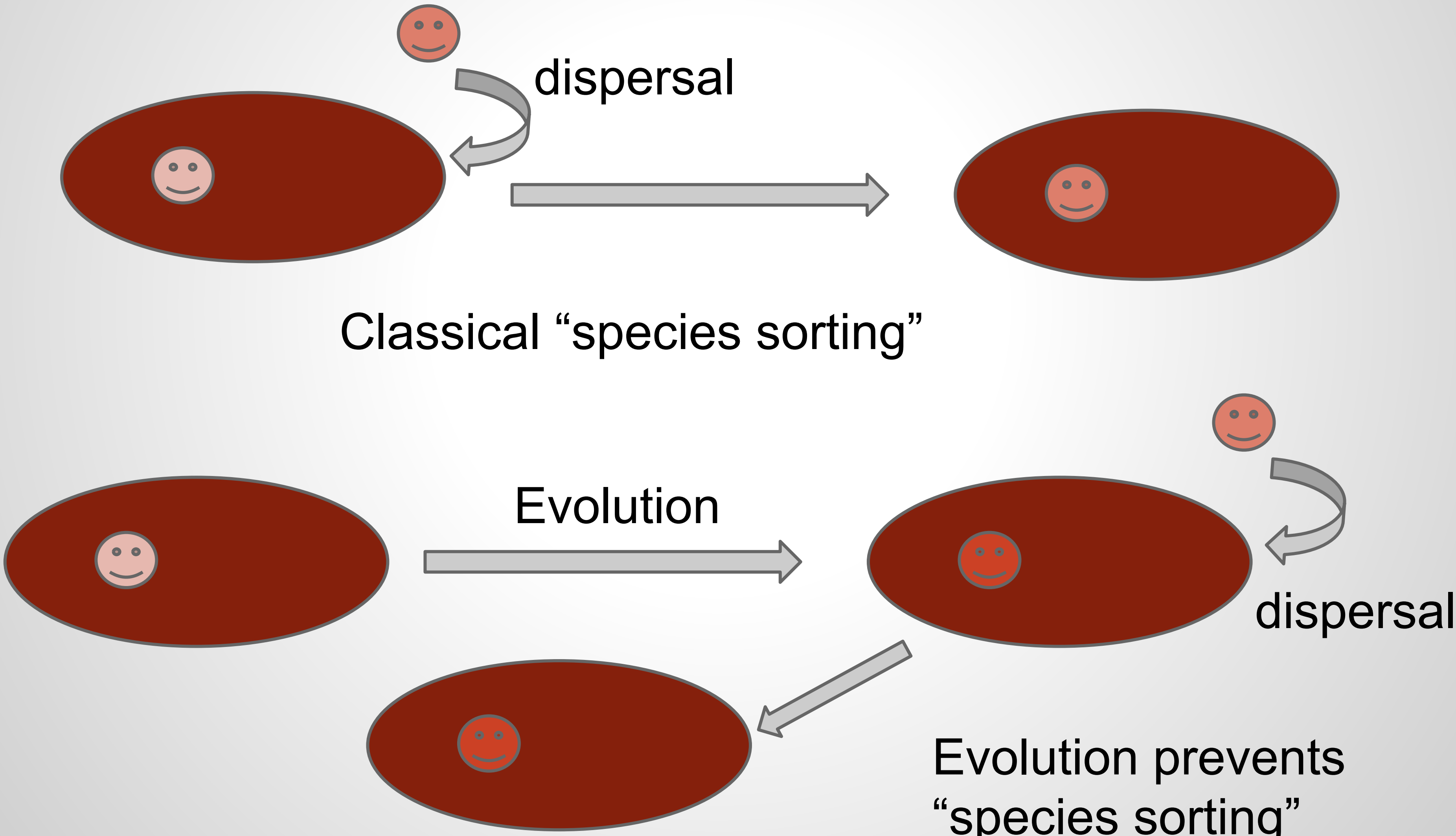
Mouquet & Loreau 2003





The Monopolization hypothesis (de Meester et al. 2002)

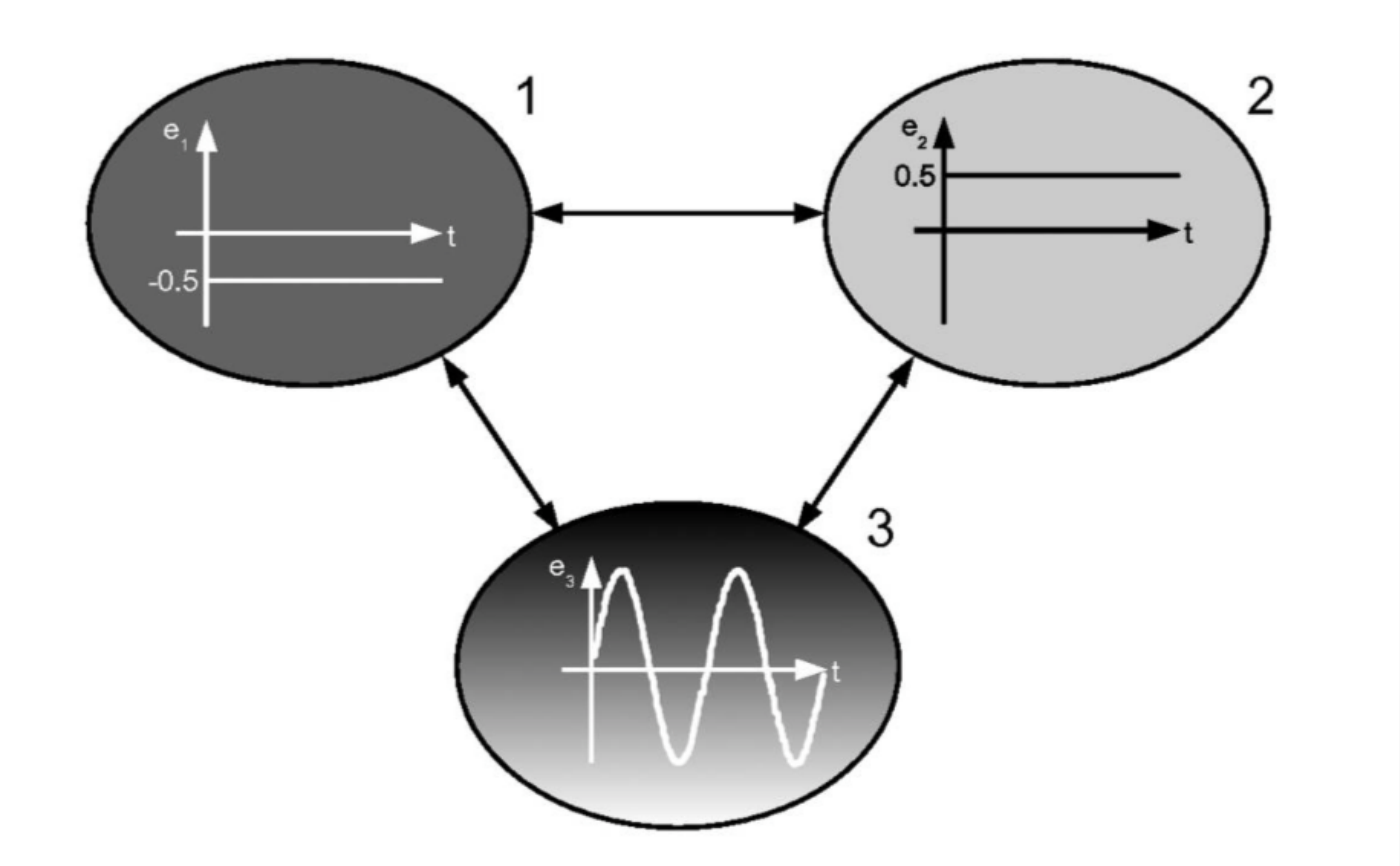
How does evolution alter diversity maintenance in metacommunities?



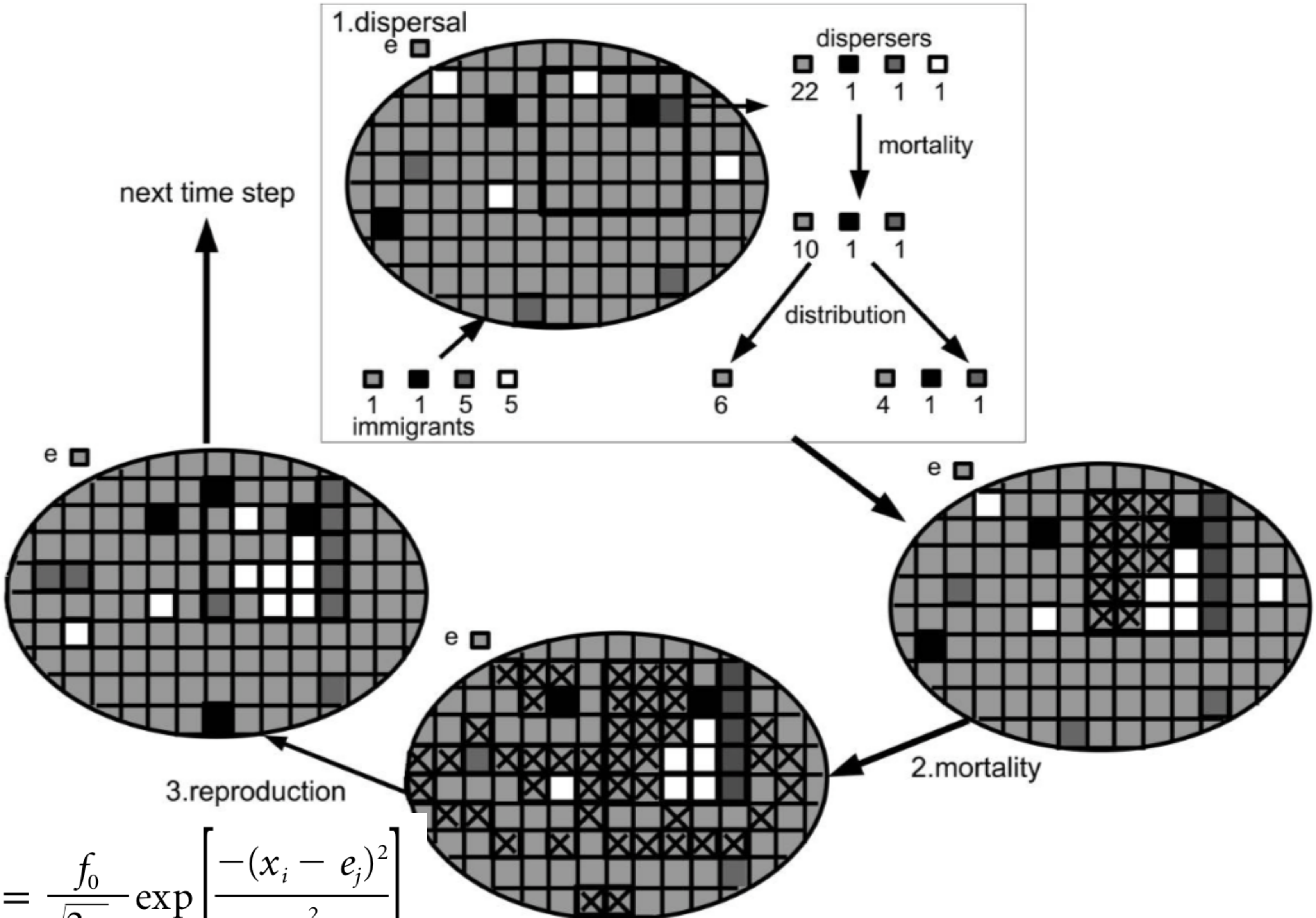
Conditions for monopolization

1. Evolution happens before dispersal
2. Environmental state is considered constant during the whole process

Given the three time scales (evolution, dispersal, environmental change), when does species sorting prevail? When does monopolization happens?

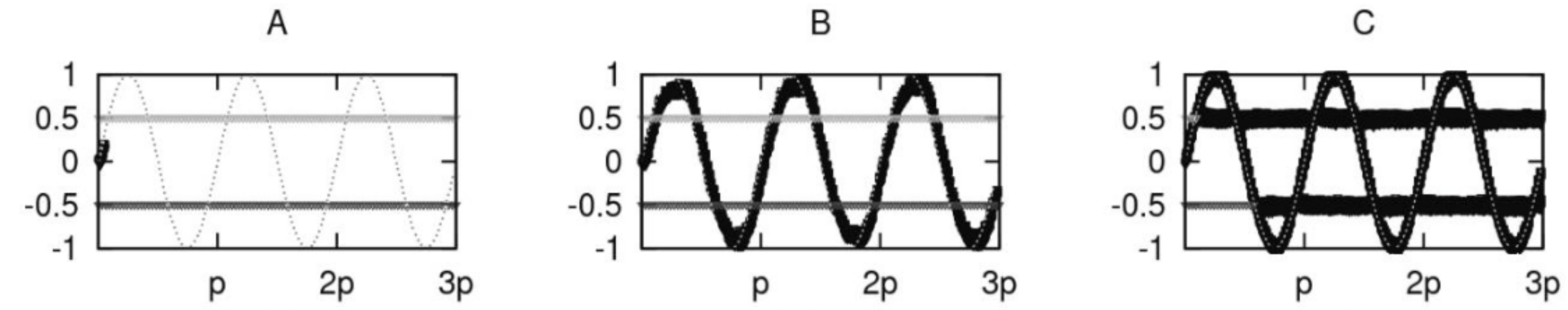


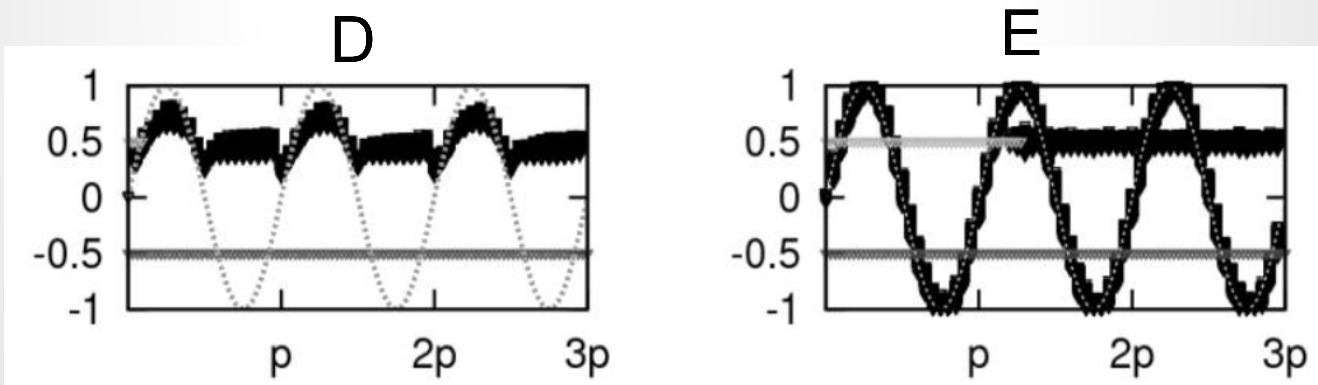
A simple, three patch model (Loeuille & Leibold 2008)



$$f(x_i, e_j) = \frac{f_0}{\sqrt{2\pi}\sigma} \exp\left[\frac{-(x_i - e_j)^2}{\sigma^2}\right]$$

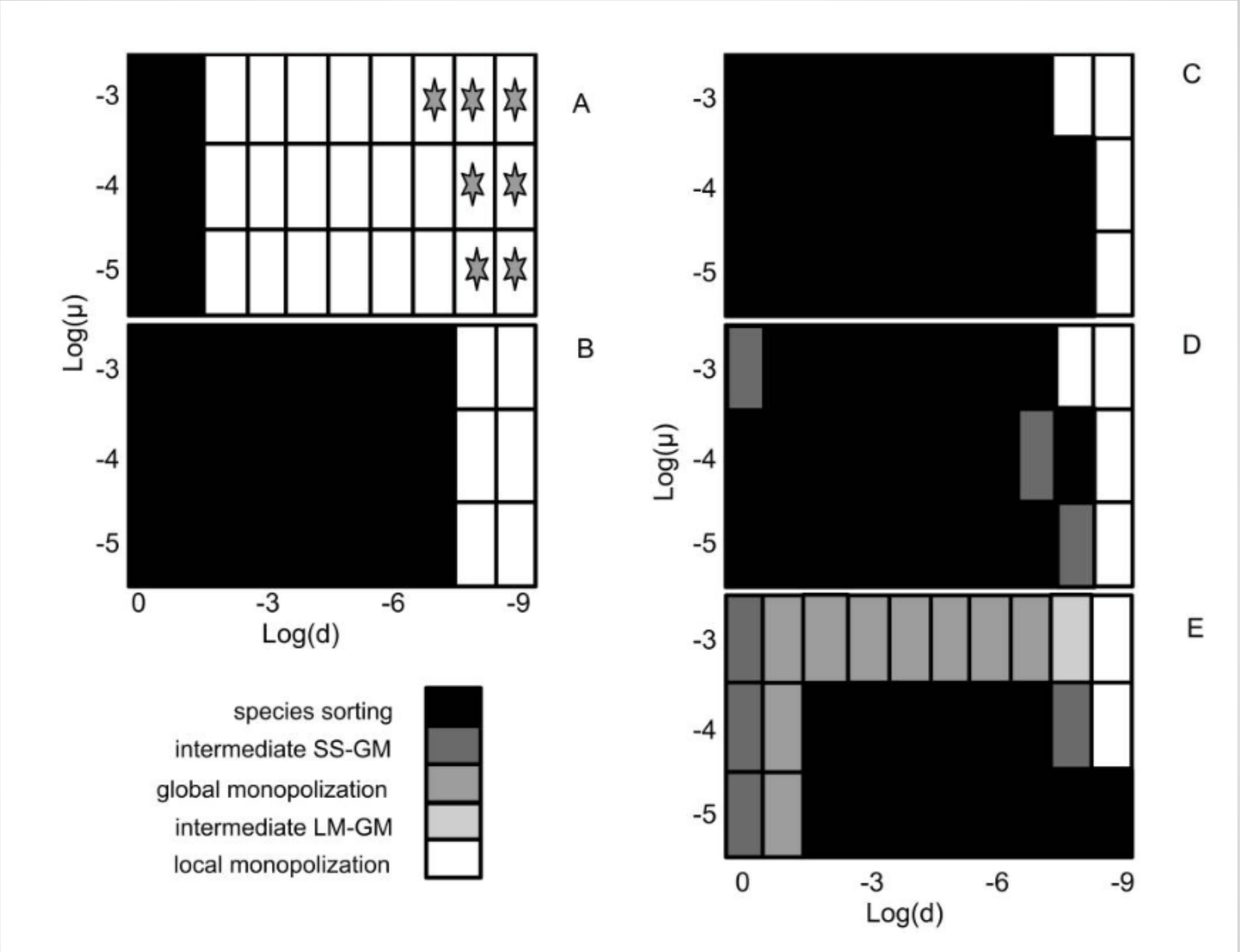
Dynamics within a single time step





Possible eco-evolutionary dynamics

Fast environmental change



Slow environmental change

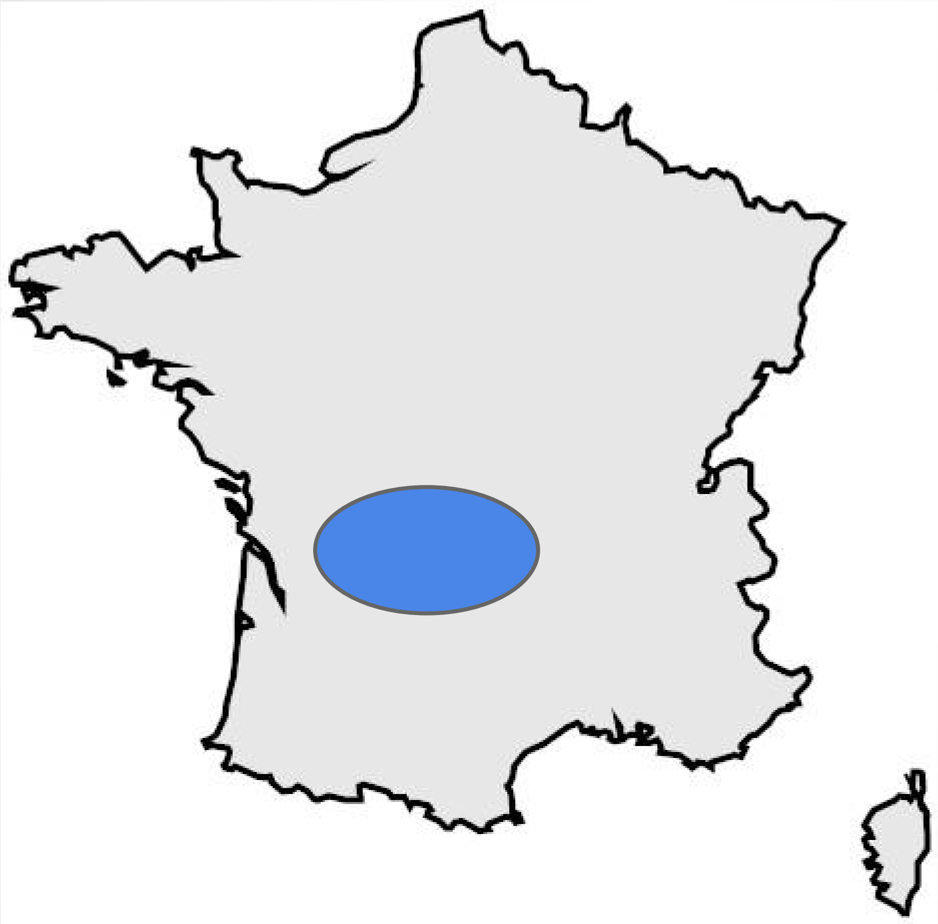
On the importance of relative timescales

Main Conclusions

1. Species sorting usually dominates (we can often ignore evolutionary dynamics)
2. Monopolization dominates for very fast environmental changes or when dispersal is small
3. Global monopolization and intermediate scenarios are possible, but require slow environmental change

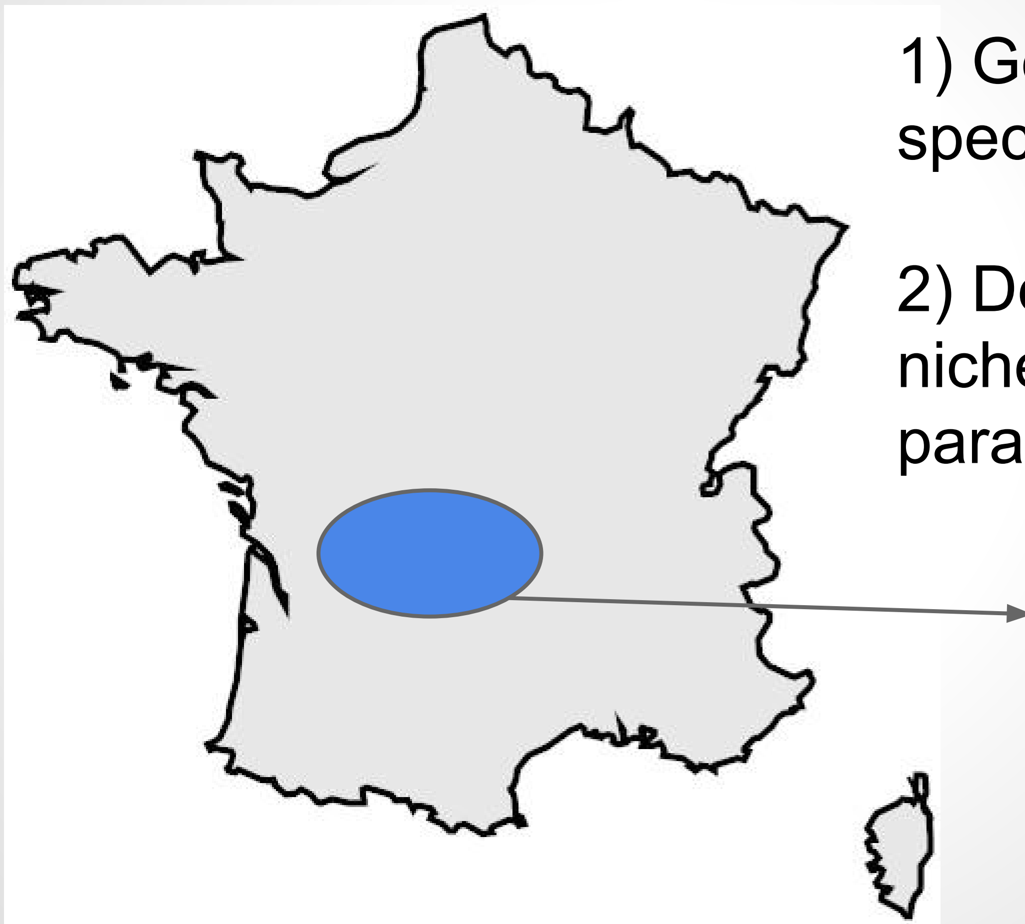
Evolution and biodiversity under climate change

Basis for predictions: climate envelop models



1) Get the current species distribution

Basis for predictions: climate envelop models

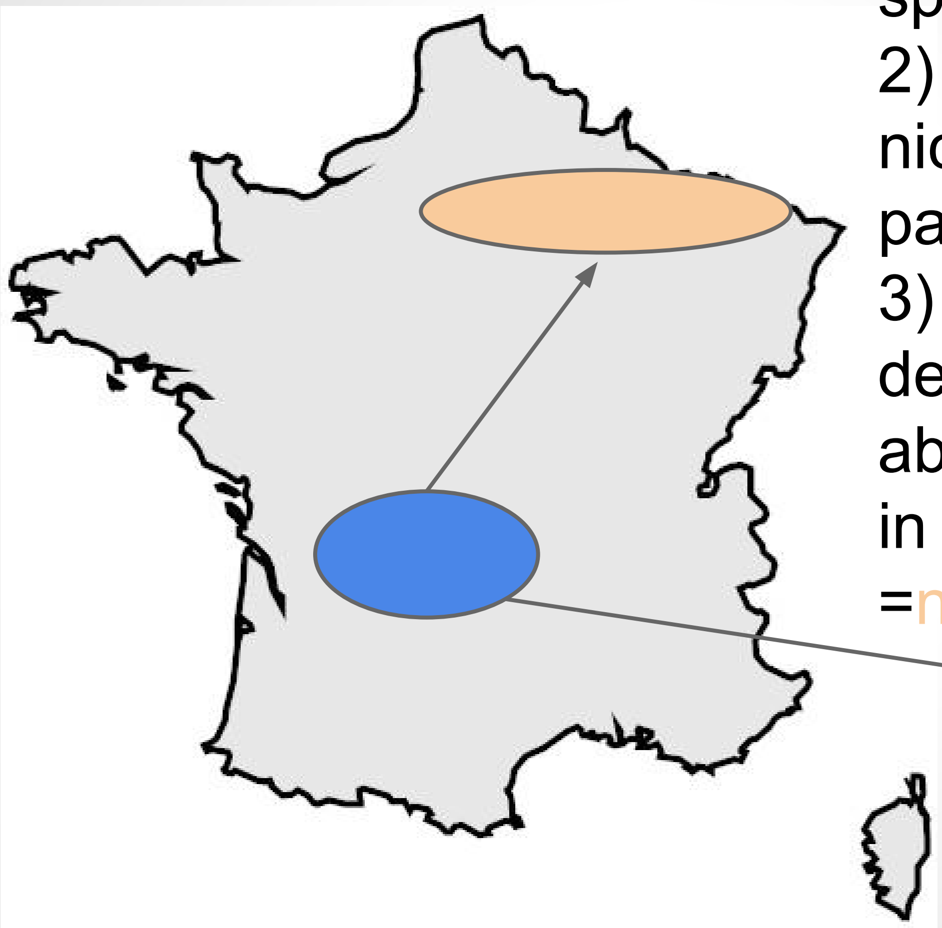


1) Get the current species distribution

2) Define the species niche, using abiotic parameters

T_{win}=5°C
T_{sum}=25°C
rain=800mm

Basis for predictions: climate envelop models



1) Get the current species distribution
2) Define the species niche, using abiotic parameters
3) Use a climate model to determine where these abiotic conditions will be in the future
=new distribution

T_{win}=5°C
T_{sum}=25°C
rain=800mm

Different use of such climate envelop models

1) Determine which species are more likely to go extinct (Thuiller et al. 2005)

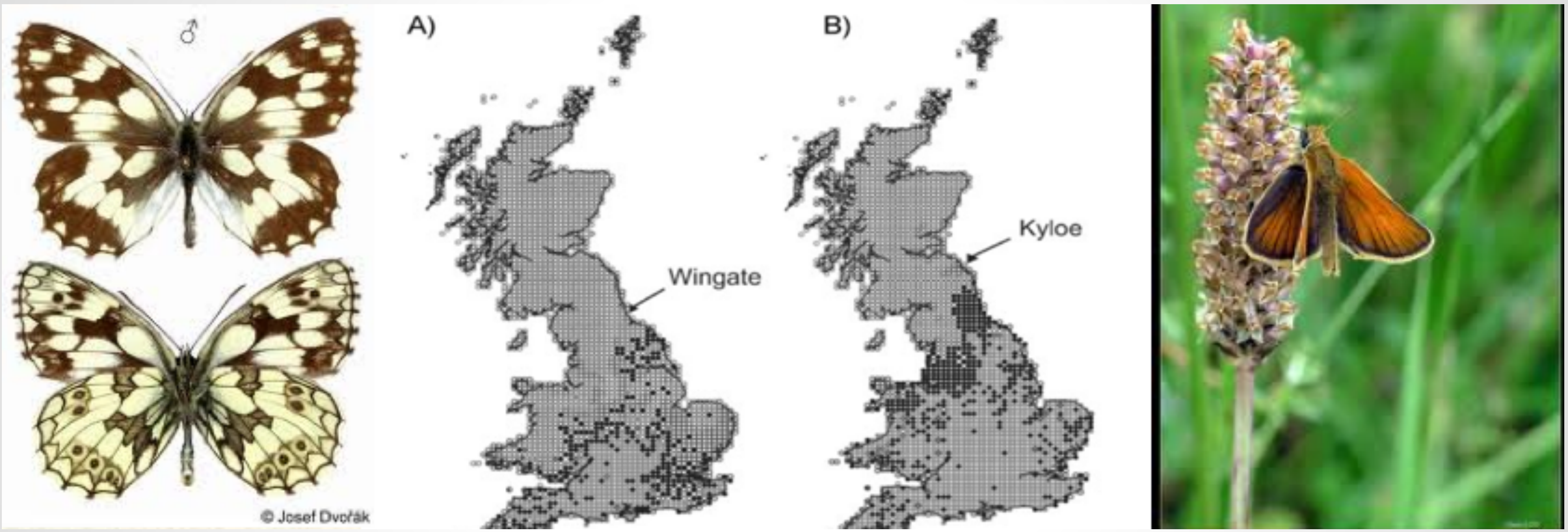
2) Determine the global extinction impact of global change (Thomas et al. 2004, Bellard et al. 2012)

3) Determine species distribution changes (Parmesan & Yohe 2003, Guisan & Thuiller 2005)

4) Assessment of future invasive species (Bertelsmeier et al. 2015)

5) Tool for assisted colonization (Willis et al. 2004, Thomas et al. 2011)

Use of climate envelop modelling

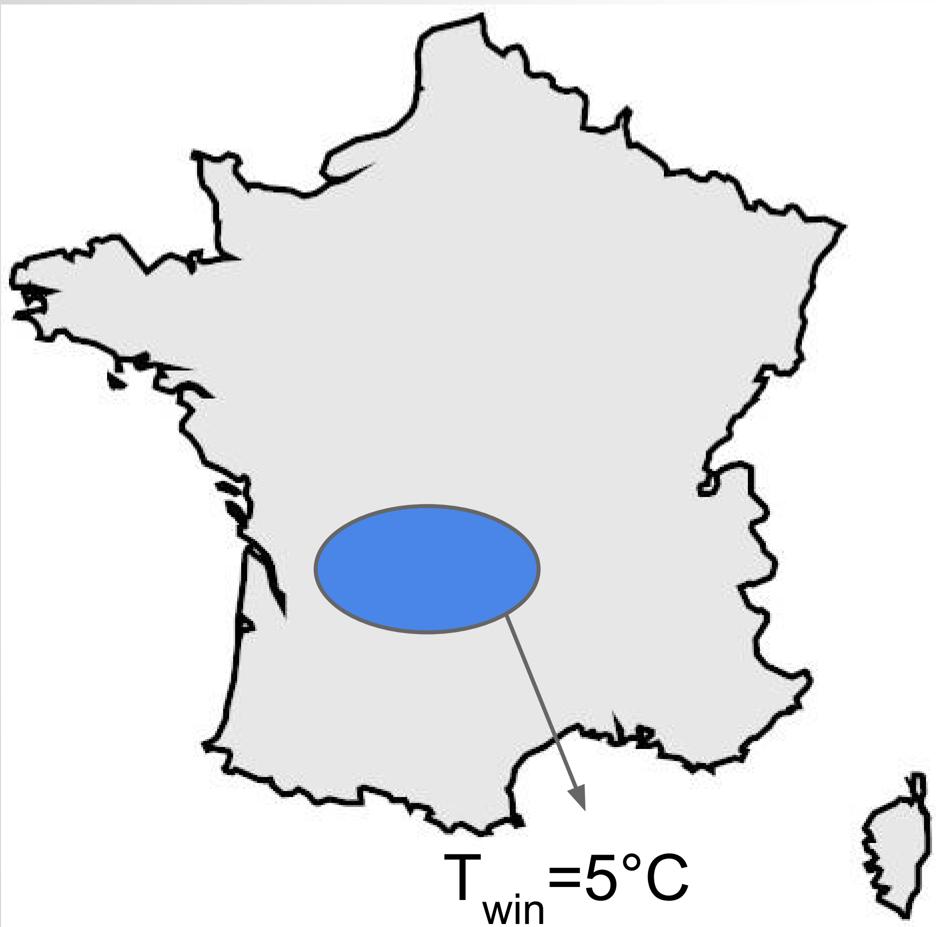


Willis et al. 2004

Assisted colonization for two species of butterflies

Possible side effects (ecological? evolutionary?)

Limit of the modelling approach: determination of the niche



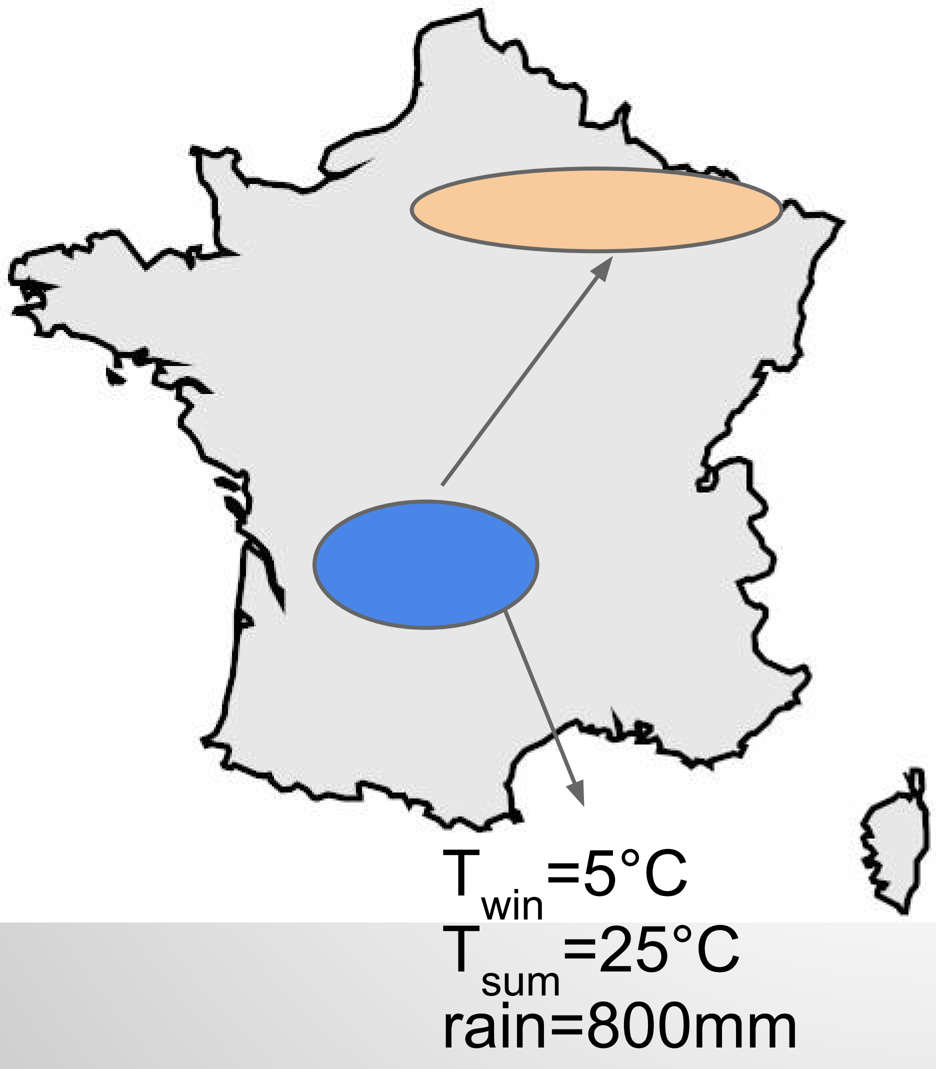
-Limit 1: Are we sure we have the relevant abiotic parameters? (Crimmins et al. 2011)

-Limit 2: Is the species distribution representative of the niche? (Davis 1998)

-Limit 3: What about biotic components?

(Valiente Banuet et al. 2006)

Limit of the modelling approach: determination of the new range



-Limit 1: Limits of prediction for the climate model for the chosen combination of abiotic parameters

-Limit 2: Will the species be able to reach the new range?

Some crucial hypotheses

-Species are studied one by one, so that interactions between species play no role in the predicted distribution

-Climate niche is fixed, no evolution (niche conservatism)

-No dispersal limitation

corollary 1: the higher the dispersal of species, the better it will face global change

corollary 2: Higher dispersal, higher diversity

What components should be added?

1) Role of interspecific interactions. No plants without their pollinators or seed dispersers. Species cannot install if a strong competitor or predator is present, etc.

2) The role of evolution. Climate change is large scale, and may exert strong selective pressures. Evolution should be expected for many species.

see Lavergne et al. 2010

Balanya et al. 2006

Pandolfi et al. 2011

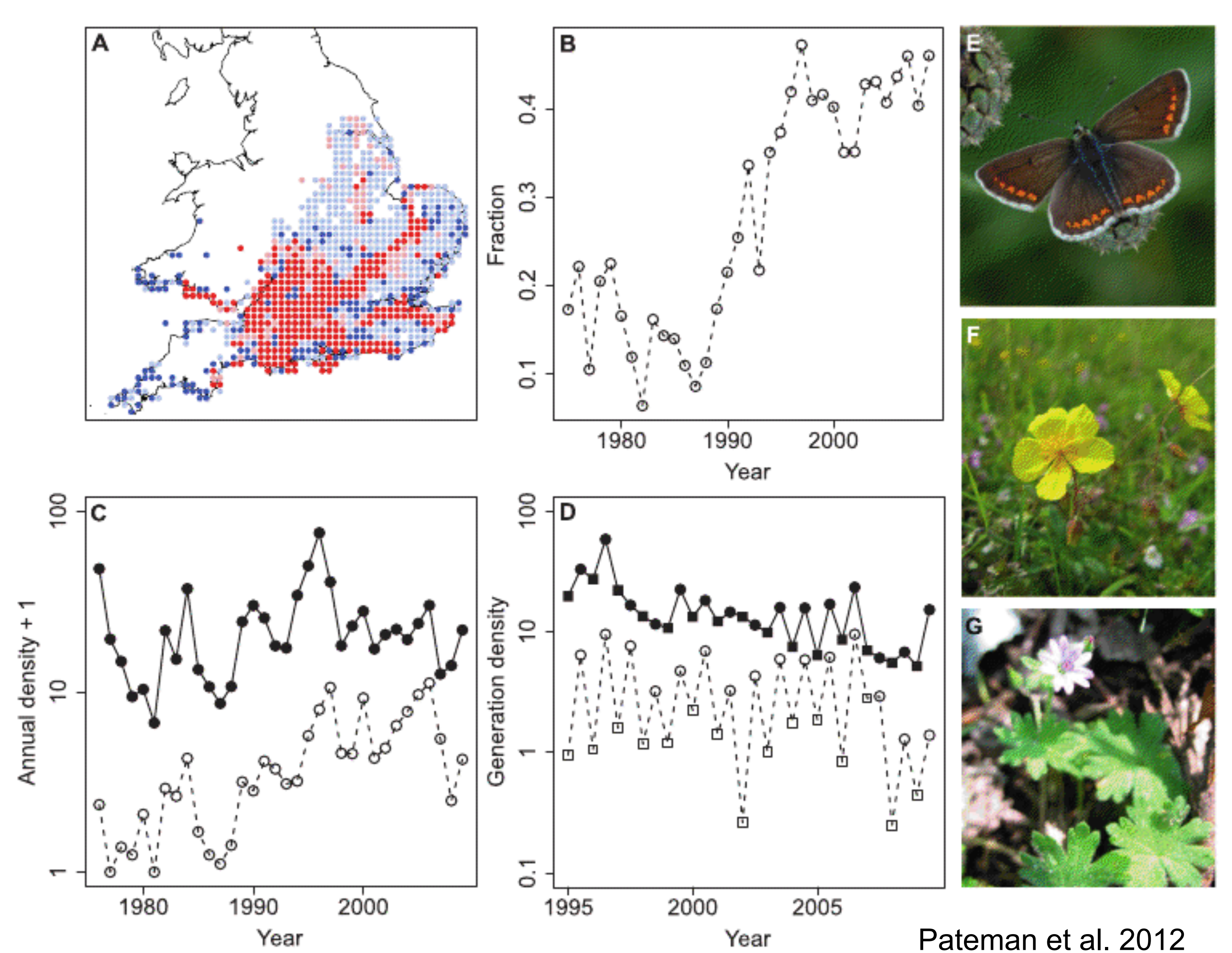
Nussey et al. 2005
Husby et al. 2011

Jonzen et al. 2006

Phillimore et al. 2010

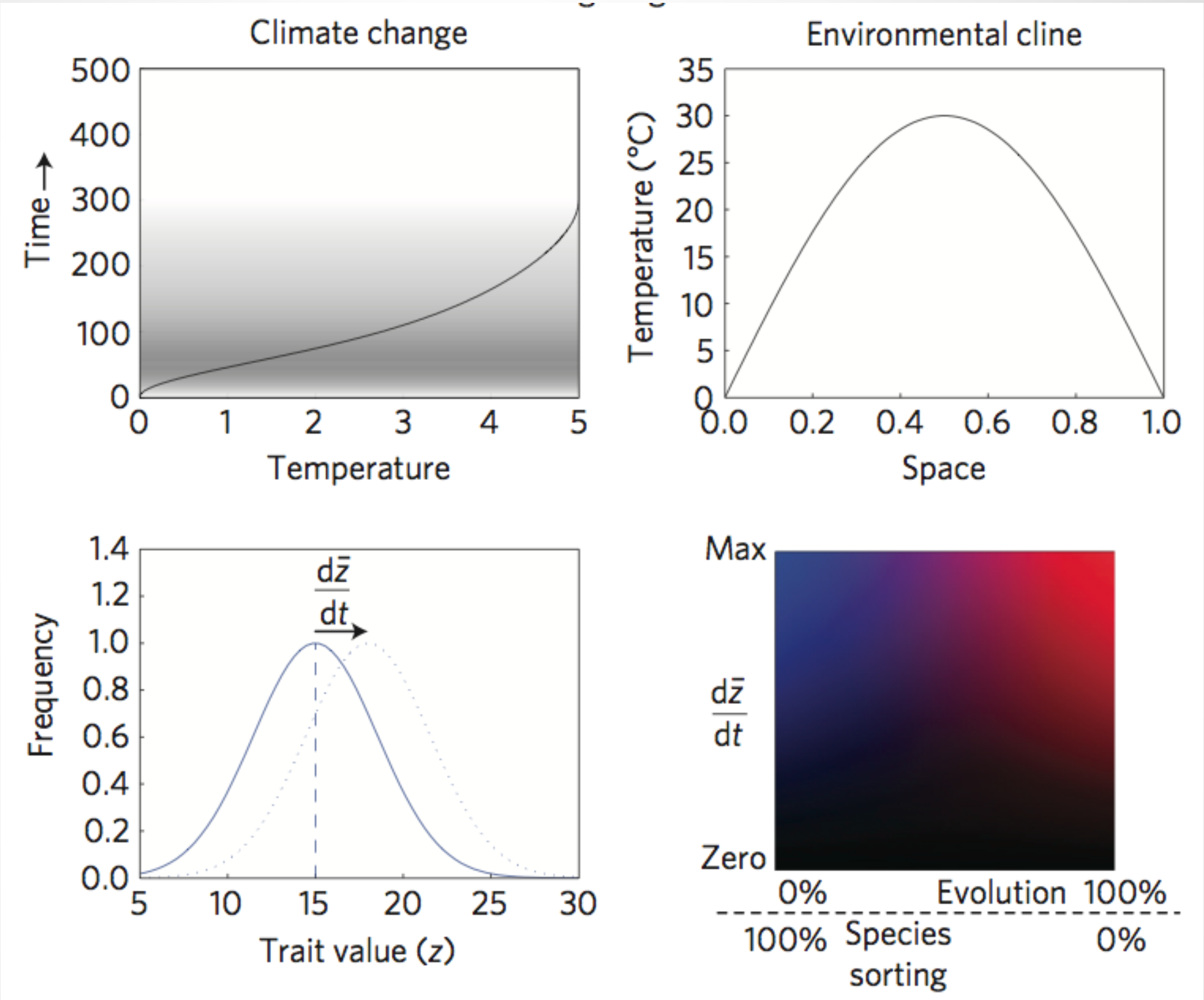
Franks et al. 2007

One possible example



Pateman et al. 2012

Hypotheses of the model



Related equations

$$\frac{\partial N_i}{\partial t} = g_i N_i + \frac{1}{2} V_i \frac{\partial^2 g_i}{\partial z^2}\bigg|_{z=z_i} N_i + D_i \frac{\partial^2 N_i}{\partial x^2}$$

$$\begin{bmatrix}\text{change in}\\ \text{population}\end{bmatrix} = \begin{bmatrix}\text{population}\\ \text{dynamics}\end{bmatrix} + \begin{bmatrix}\text{genetic}\\ \text{load}\end{bmatrix} + [\text{dispersal}]$$

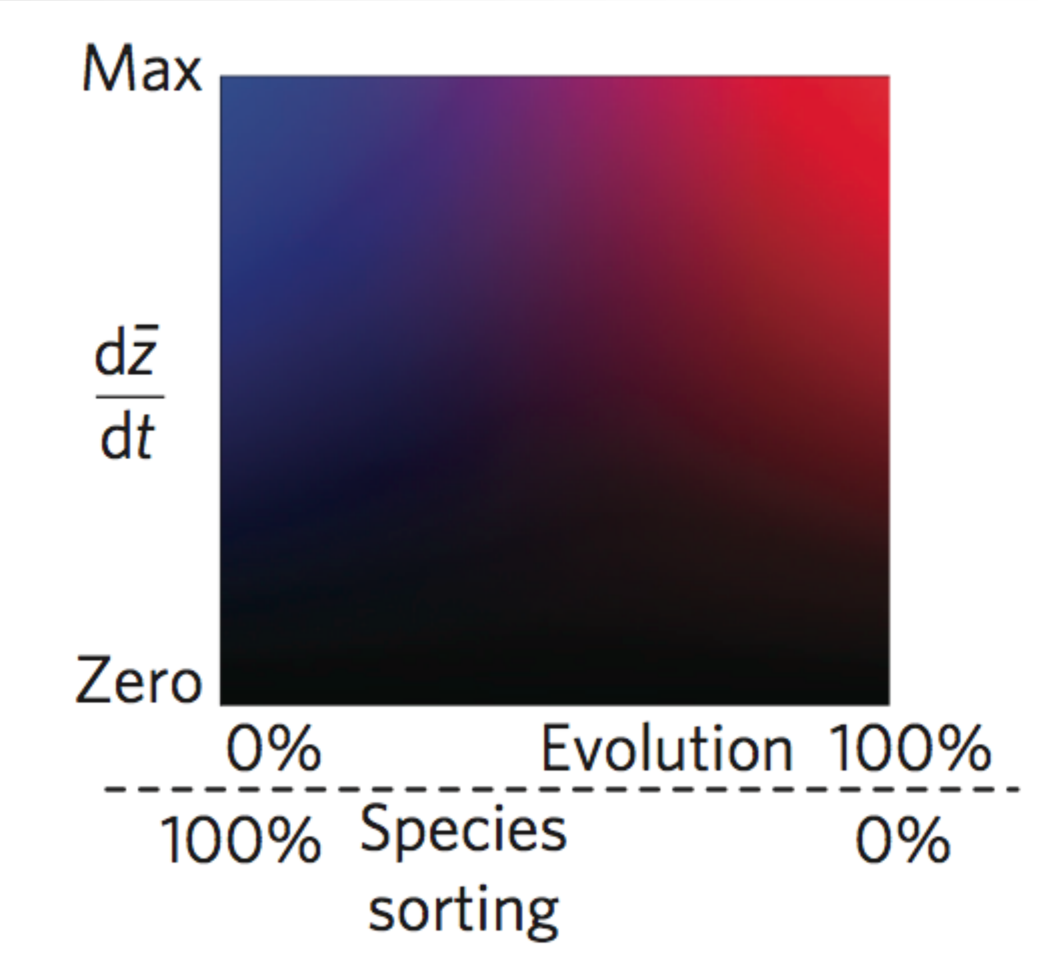
$$g_i(x,t) = r_i(x,t)\left(1 - \sum_I \alpha_{ij} N_i(x,t)\right) - m$$

$$r_i(x,t) = r_{\max} \exp\left(\frac{-\left(TC(x,t) - z_i(x,t)\right)^2}{w^2}\right)$$

$$\frac{\partial z_i}{\partial t} = q_i V_i \frac{\partial g_i}{\partial z}\bigg|_{z=z_i} + D_i \left(\frac{\partial^2 z_i}{\partial x^2} + 2 \frac{\partial \log N_i}{\partial x} \frac{\partial z_i}{\partial x}\right)$$

$$\begin{bmatrix}\text{change}\\ \text{in trait}\end{bmatrix} = \begin{bmatrix}\text{directional}\\ \text{selection}\end{bmatrix} + \begin{bmatrix}\text{gene}\\ \text{flow}\end{bmatrix}$$

Trait Change

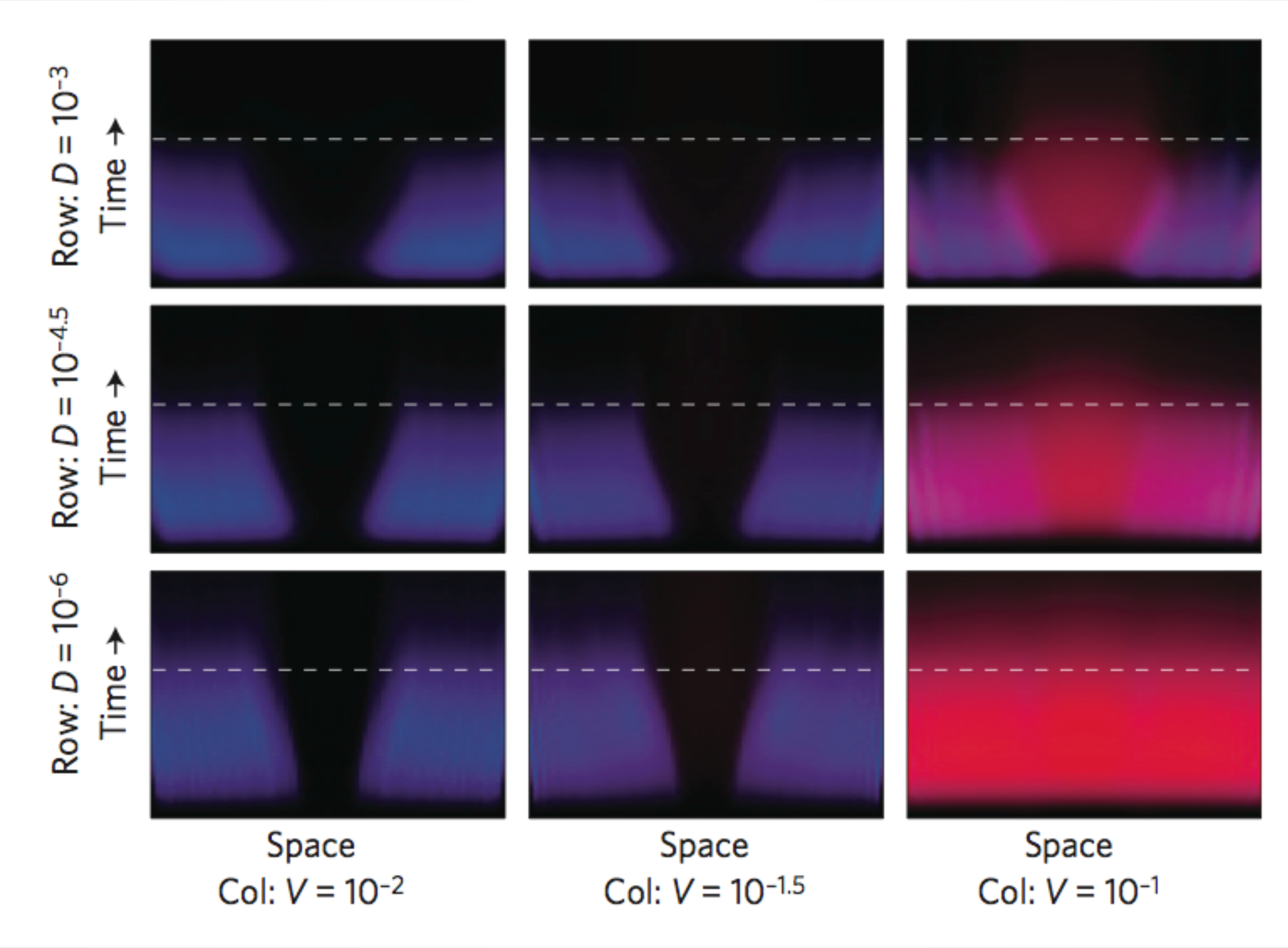


Possible cause of change in average local trait:

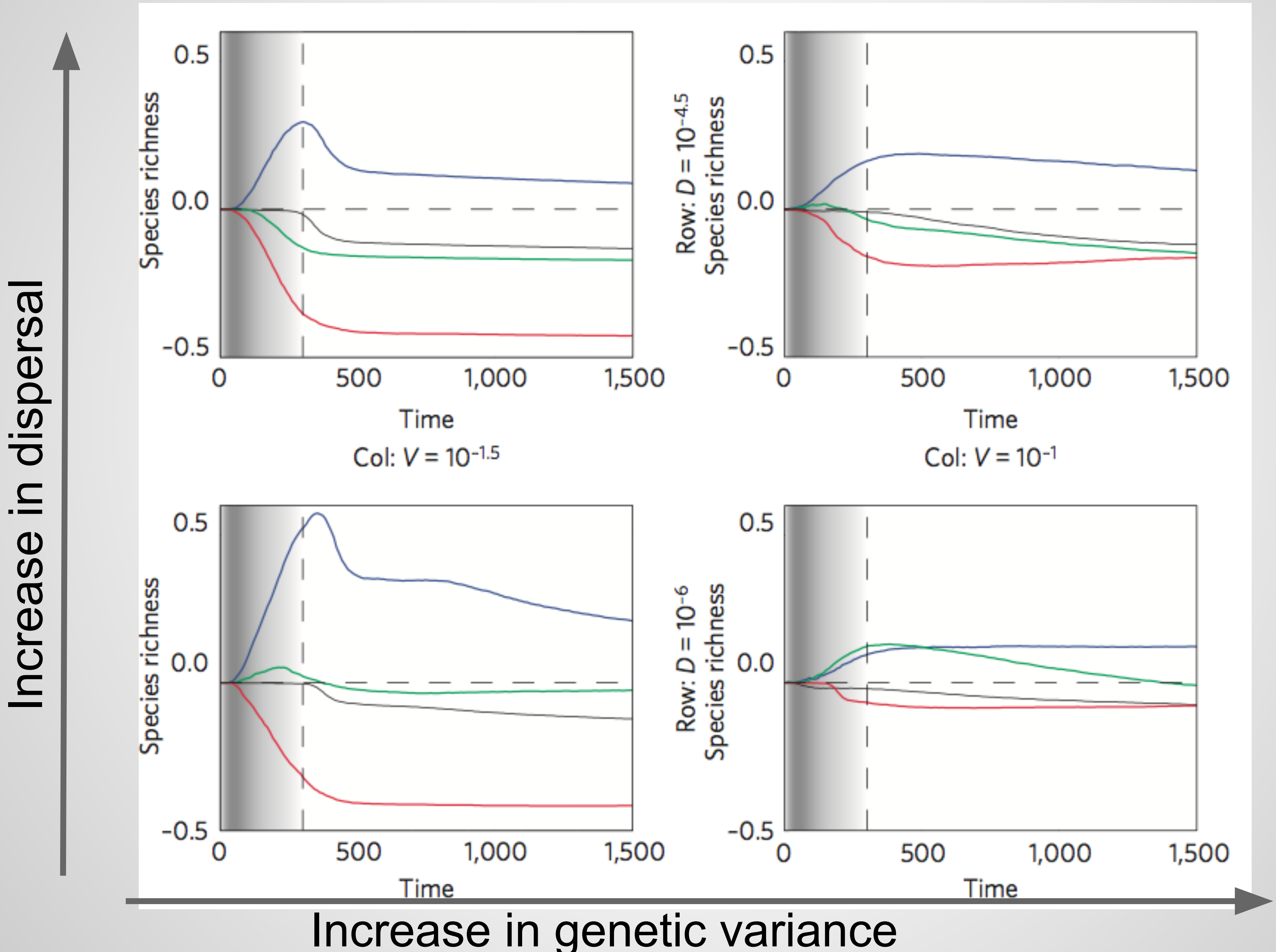
-species sorting (replacement of species of one trait by species of another trait)

-evolution (within species change in the trait)

When does evolution matter more than ecological sorting?



Effects of evolution on diversity



Conclusions

1) Extinction debt: the worse may be ahead

2) Evolution should not be seen systematically as positive for biodiversity

3) Climate envelop models should be taken with caution (eg, the idea that increasing dispersal will save biodiversity is clearly false once competition is considered)

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