Evolutionary responses of ecosystems to climate warming - insights from a food web model approach

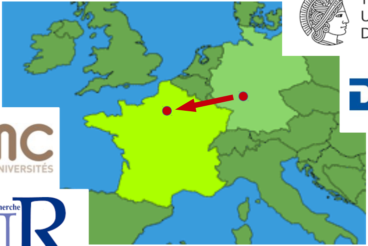
http://www.gsmnation.com/blog/2013/02/28/iphone-6-rumors/

Barbara Drossel

TECHNISCHE UNIVERSITÄT DARMSTADT

DFG

DFG Research Unit 1748
“networks on networks”
www.for1748.de



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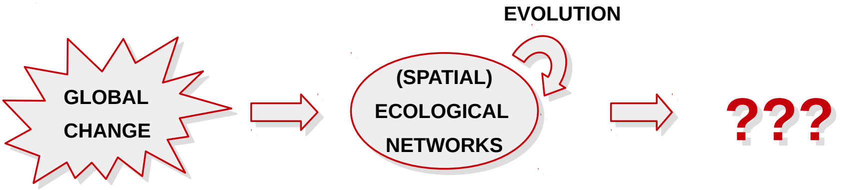
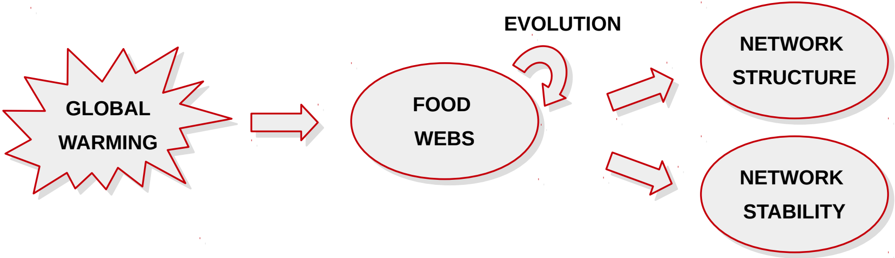
Agence Nationale de la Recherche ANR

ANR funded project:
“Adaptation and Resilience of Spatial Ecological Networks to human-Induced Changes”
ARSENIC

The big picture



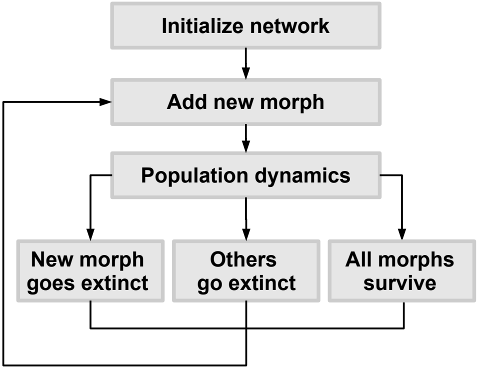
The big picture



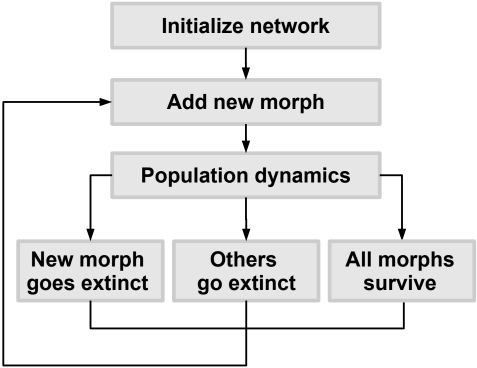
Overview

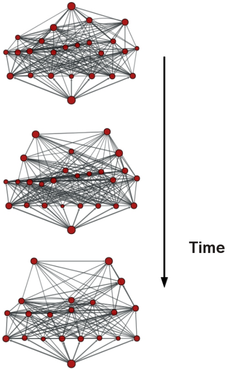
1. Introduction to evolutionary food web models
2. The impact of temperature on food web structure and stability
3. Robustness checks
4. Work in progress

What is an evolutionary food web model?



What is an evolutionary food web model?





A famous example based only on body masses...

PNAS

Evolutionary emergence of size-structured food webs

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Edited by Simon A. Levin, Princeton University, Princeton, NJ, and approved March 10, 2005 (received for review November 12, 2004)

Explaining the structure of terrestrial and aquatic food webs remains one of the most important challenges of ecological theory. Most existing models use emergent properties of food webs, such as diversity and connectance as parameters, to determine other food-web descriptors. Lower-level processes, in particular adaptation (whether by behavioral, developmental, or evolutionary mechanisms), are usually not considered. Here, we show that complex, realistic food webs may emerge by evolution from a single ancestor based on very simple ecological and evolutionary rules. In our model, adaptation acts on body size, whose impact on the metabolism and interactions of organisms is well established. Based on parameters defined at the organism scale, the model predicts emergent properties at the food-web scale. Variations of two key parameters (width of consumption niche and competition intensity) allow very different food-web structures and functionings to emerge, which are similar to those observed in some of the best-documented food webs.

complex adaptive system | evolutionary assembly | macroevolution | food-web structure

Although prevailing food-web models, such as the cascade model (1, 2), the niche model (3), and the more recent nested-hierarchy model (4), are able to describe food-web structure satisfactorily, they fail to provide clear mechanisms explaining how this structure emerges. There are two reasons for this shortcoming. First, these models are parameterized by using some emergent properties of observed food webs (usually diversity and connectance), although these properties result from lower-level processes. Second, they consider only binary food webs in which species and trophic links are either present or absent, but are not quantified. The dynamical aspects of food webs, linked to population dynamics and adaptation processes, although ubiquitous in ecosystems (5), are absent from these theoretical studies.

metabolism is measured per unit mass (mass-specific metabolic rate) (13). Because of this allometric relation, it is possible to correlate body size and a number of life-history traits of organisms, thereby making a link between organismic and community scales (13, 14). We modeled the population dynamics of species i with biomass N_i and body size x_i by

$$\frac{dN_i}{dt} = N_i\left(f(x_i)\sum_{j=0}^{i-1}\gamma(x_i - x_j)N_j - m(x_i) - \sum_{j=1}^{n}\alpha(|x_i - x_j|)N_j - \sum_{j=i+1}^{n}\gamma(x_j - x_i)N_j\right). \quad [1]$$

where the x_i are ranked by increasing values, $f(x_i)$ is the production efficiency of species i, and $m(x_i)$ is its mass-specific mortality rate. Because these two parameters are related directly to mass-specific metabolic rate, they are assumed to depend on body size (13): $f(x_i) = f_0 x_i^{-0.25}$ and $m(x_i) = m_0 x_i^{-0.25}$.

The function $\gamma(x_i - x_j)$ describes the consumption rate exerted by predator i on prey j. It is assumed to be a Gaussian function with standard deviation s and a maximum value when the body sizes of the predator and the prey are separated by a distance d as follows:

$$\gamma(x_i - x_j) = \frac{\gamma_0}{s\sqrt{2\pi}}\exp\left[\frac{-(x_i - x_j - d)^2}{s^2}\right],$$

with $x_i > x_j$ (Fig. 1). The choice of this type of function is based on the idea that, for a predator of a given size, energy gains should increase with its prey body size, whereas the probability of such successful attacks should decrease with the prey body size. As a result, body size should then be optimum at an intermediate value. This type of relationship between interaction

… and another example based on three traits

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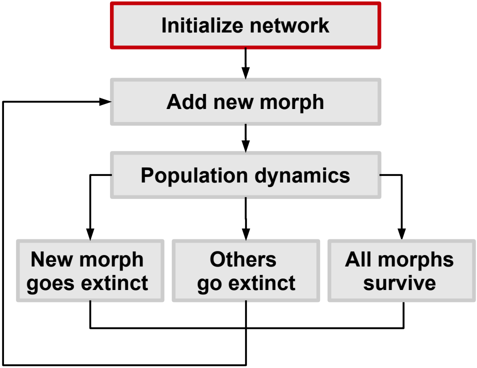
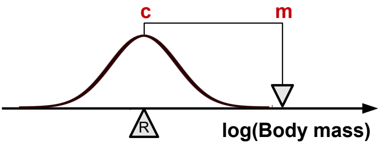
Evolutionary food web model based on body masses gives realistic networks with permanent species turnover

K.T. Allhoff[1], D. Ritterskamp[2], B.C. Rall[3], B. Drossel[4] & C. Guill[5]

The networks of predator-prey interactions in ecological systems are remarkably complex, but nevertheless surprisingly stable in terms of long term persistence of the system as a whole. In order to understand the mechanism driving the complexity and stability of such food webs, we developed an eco-evolutionary model in which new species emerge as modifications of existing ones and dynamic ecological interactions determine which species are viable. The food-web structure thereby emerges from the dynamical interplay between speciation and trophic interactions. The proposed model is less abstract than earlier evolutionary food web models in the sense that all three evolving traits have a clear biological meaning, namely the average body mass of the individuals, the preferred prey body mass, and the width of their potential prey body mass spectrum. We observed networks with a wide range of sizes and structures and high similarity to natural food webs. The model networks exhibit a continuous species turnover, but massive extinction waves that affect more than 50% of the network are not observed.

The evolutionary algorithm





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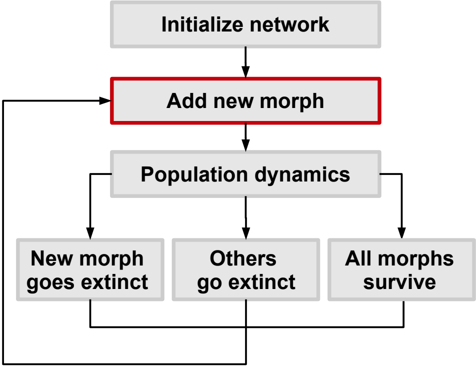

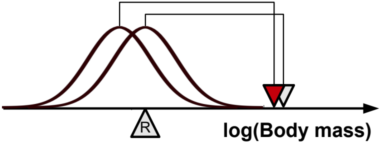

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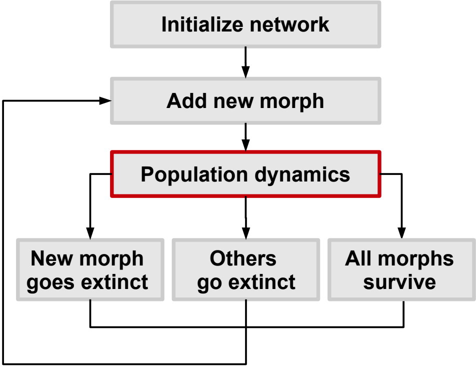
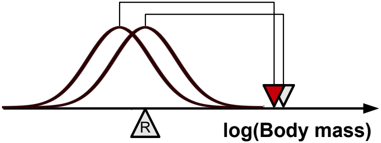
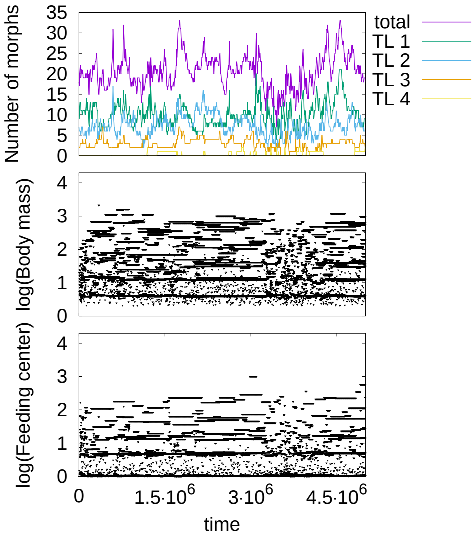




$$\frac{dB_i}{dt} = \sum_j \left(\epsilon a_{ij} - a_{ji}\right) B_i B_j - d_i B_i - \sum_{k=1} c_{ik} B_i B_k$$

Examplary simulation run



Overview

The Arrhenius equation

- Morph i's respiration and mortality rate

$$d_i(T) \propto \exp\left(+\frac{E_{\text{act}} \cdot (T - T_0)}{kTT_0}\right)$$

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- Resource growth rate

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- Resource carrying capacity

$$K(T) \propto \exp\left(-\frac{E_{\mathrm{act}} \cdot (T - T_0)}{kTT_0}\right)$$

The Arrhenius equation

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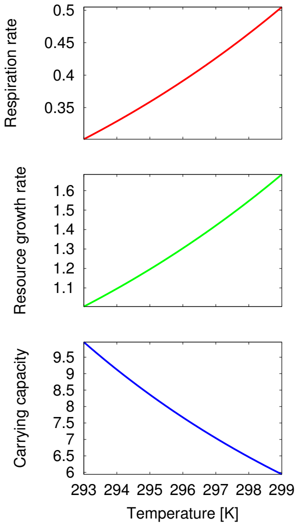
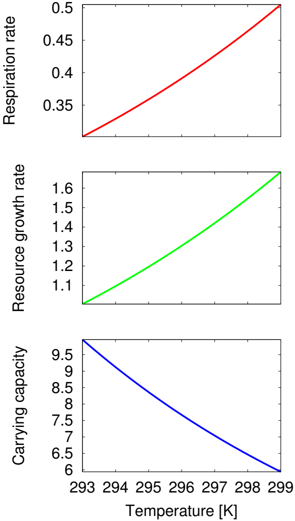
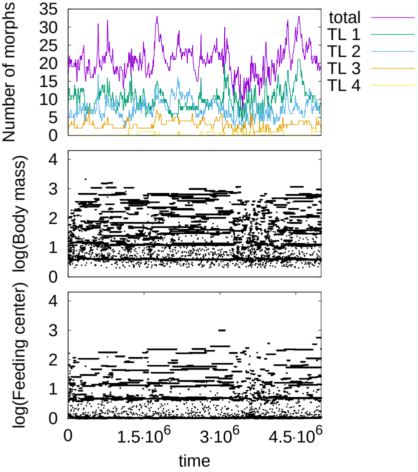


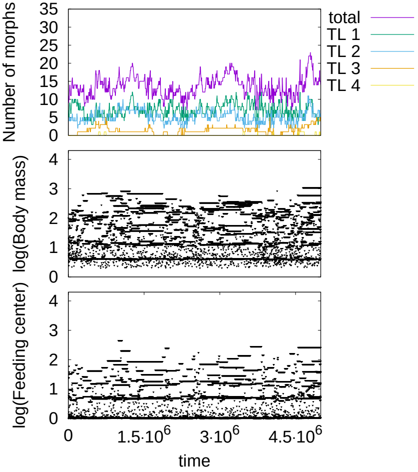
Prediction: Higher temperatures lead to...

- ...fewer trophic levels!
- ...more biomass accumulation!
- (...less biomass accumulation?)

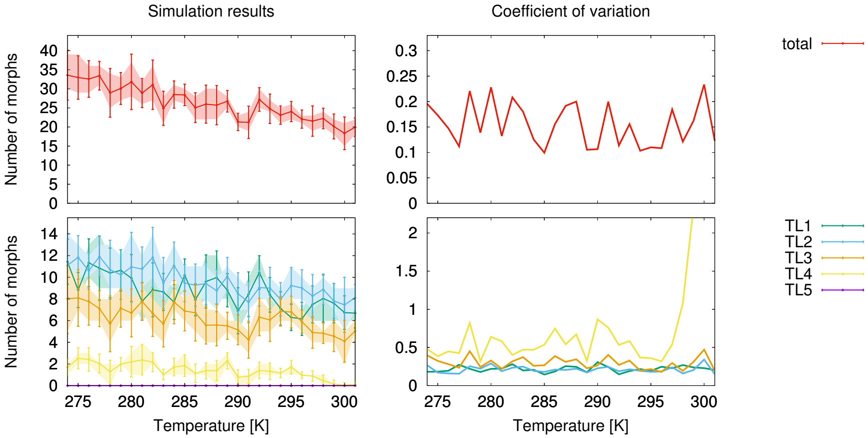


Simulations with T=280 K and T=300 K

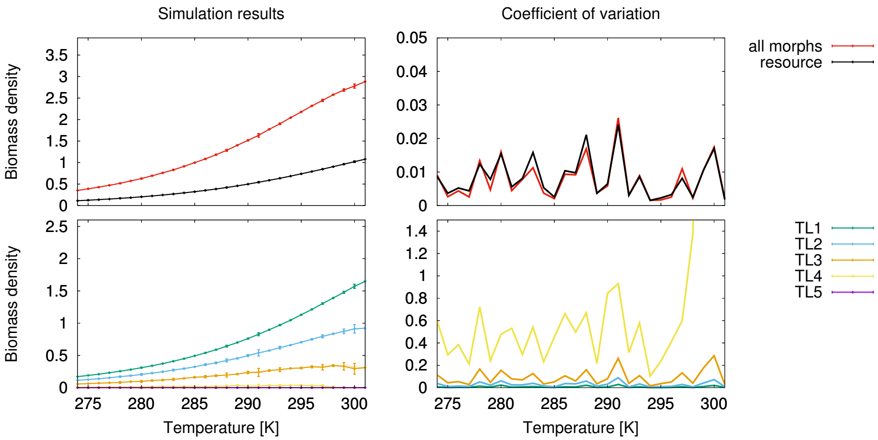




Results 1/3:
Temperature dependent network size



Results 2/3: Temperature dependent biomass accumulation



Results 3/3: Temperature dependent trait values

T $\uparrow \Rightarrow$ body mass $\downarrow$
T $\uparrow \Rightarrow$ vertical diversity $\downarrow$

Edeline et al. "Ecological emergence of thermal clines in body size." Global Change Biology (2013) 19, 30623068

Results 3/3: Temperature dependent trait values

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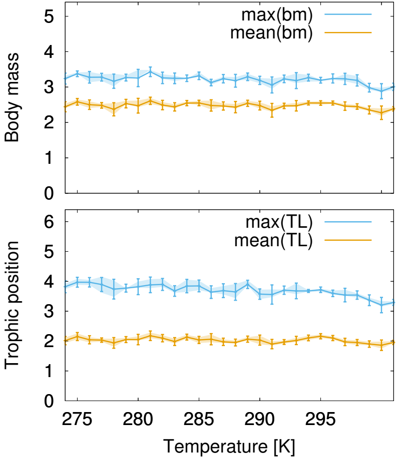

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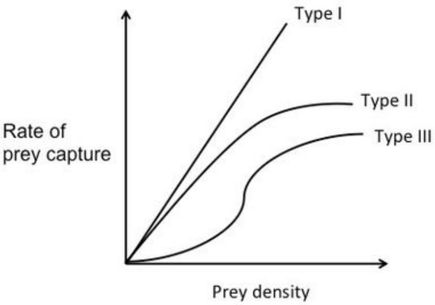
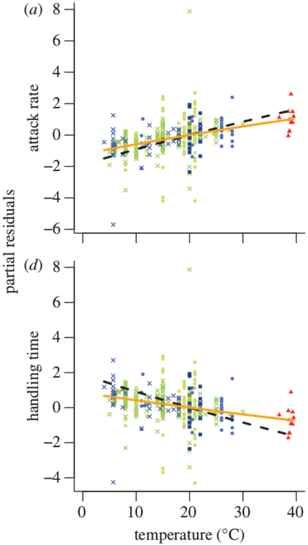
Robustness checks



www.wikipedia.org/wiki/Optimal_foraging_theory

Q1: What about other functional responses?

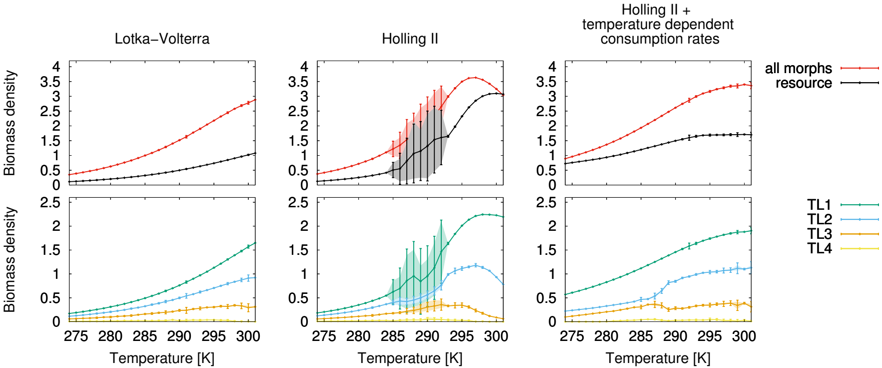
Robustness checks



Rall et al. "Universal temperature and body-mass scaling of feeding rates."
Phil. Trans. R. Soc. B 367.1605 (2012): 2923-2934.

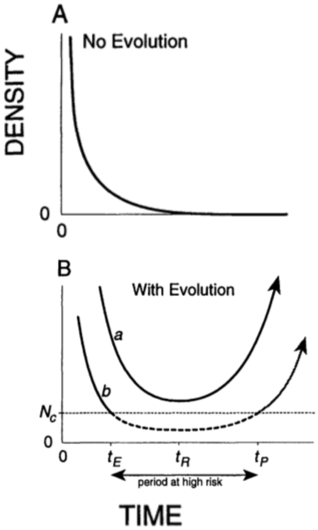
Q2: What about temperature dependent consumption rates?

Robustness checks



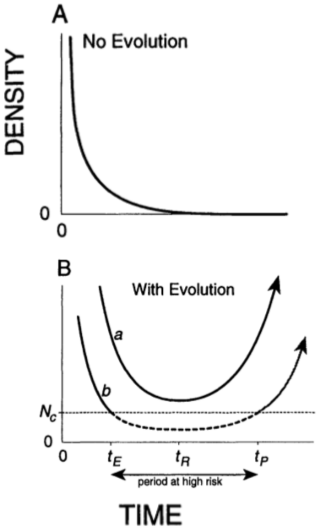
Overview

Work in progress: Dynamic responses to warming



Gomulkiewicz and Holt. "When does evolution by natural selection prevent extinction?." Evolution 49.1 (1995): 201-207.

Work in progress: Dynamic responses to warming



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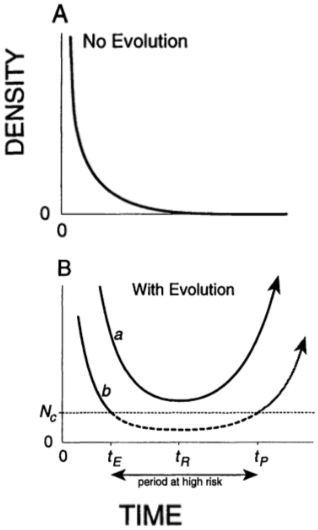
- Do we observe an evolutionary rescue effect on the network scale?

Work in progress: Dynamic responses to warming



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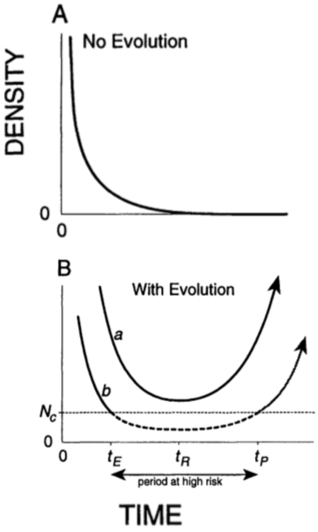
- Do we observe an evolutionary rescue effect on the network scale?
- Or do we observe an extinction debt?

Work in progress: Dynamic responses to warming



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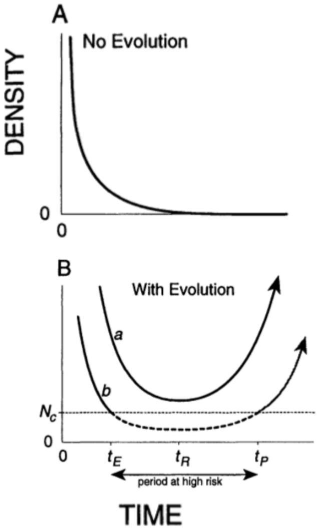
- Do we observe an evolutionary rescue effect on the network scale?
- Or do we observe an extinction debt?
- Is there a difference between short-term and long-term responses?

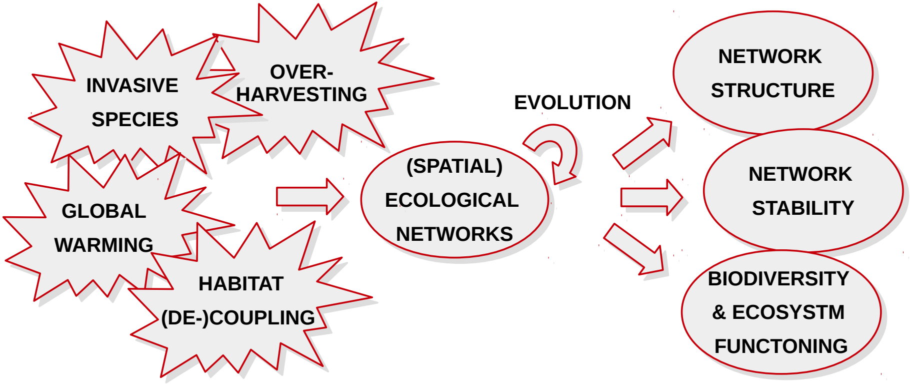
Work in progress: Dynamic responses to warming

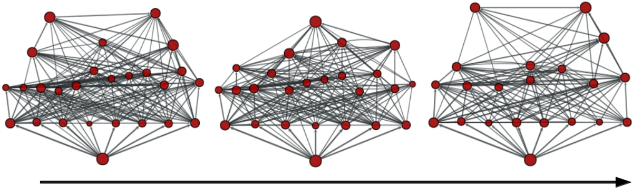


Gomulkiewicz and Holt. "When does evolution by natural selection prevent extinction?." Evolution 49.1 (1995): 201-207.

- Do we observe an evolutionary rescue effect on the network scale? **PERHAPS**
- Or do we observe an extinction debt? **YES**
- Is there a difference between short-term and long-term responses? **DEFINITELY!**

One toy, many playgrounds





Thank you for your attention! :-)

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