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science for global insight

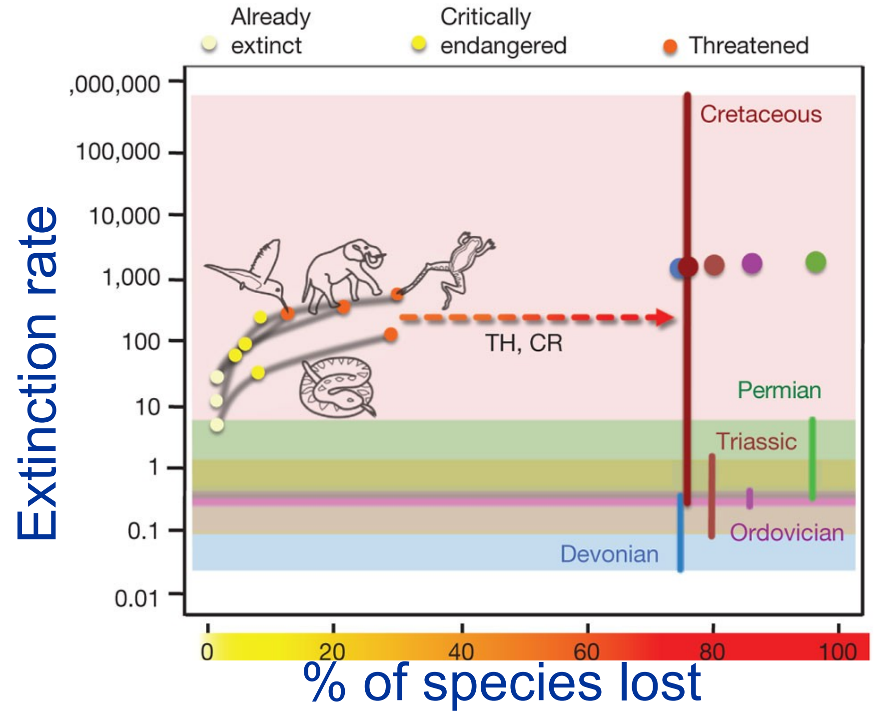
Ecosystem vulnerability to species loss: a broad study of real-world food webs.

Mateusz Iskrzyński

International Institute
for Applied Systems Analysis,
Laxenburg, Austria

25.09.2018, CSS 2018, Thessaloniki

Human-induced sixth mass extinction of species is observed.



AD Barnosky *et al. Nature* **471**, 51-57 (2011)

Extinctions endanger other parts of affected ecosystems.

the ocean agency / xl catlin seaview survey

Systemic risks in ecosystems

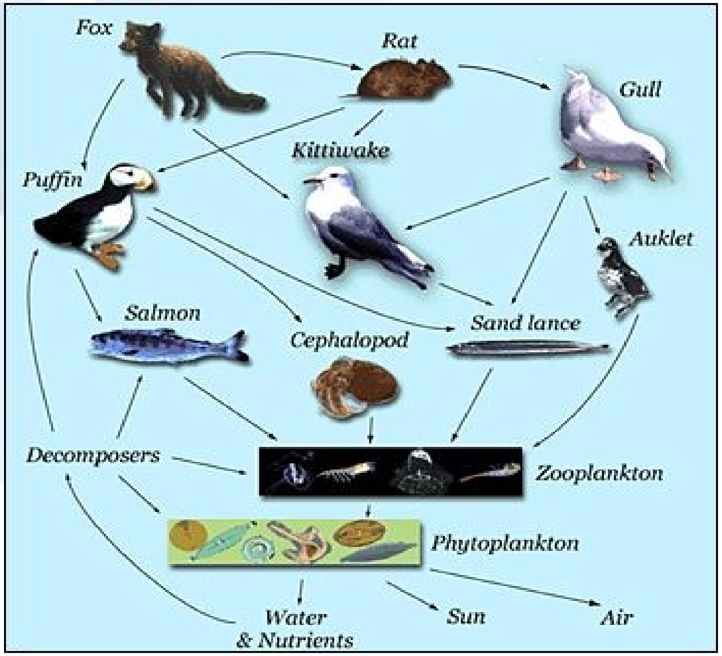
- Human-induced sixth mass extinction of species is observed.
- Extinctions endanger other parts of affected ecosystems.

Can we arrive at generalizable conclusions about their cascading effects?

Here: study feeding relationships in ecosystems (food webs) and how structure impacts vulnerability.

→ conservation policy

Trophic level



the ocean agency / xl catlin seaview survey

Originality of the approach

Large empirical sample

Jacquet, C. et al. (2016).
No complexity–stability relationship in empirical ecosystems.
Nature Communications, 7

Bane, M. S. et al. (2017).
Extinction models of robustness for weighted ecological networks.

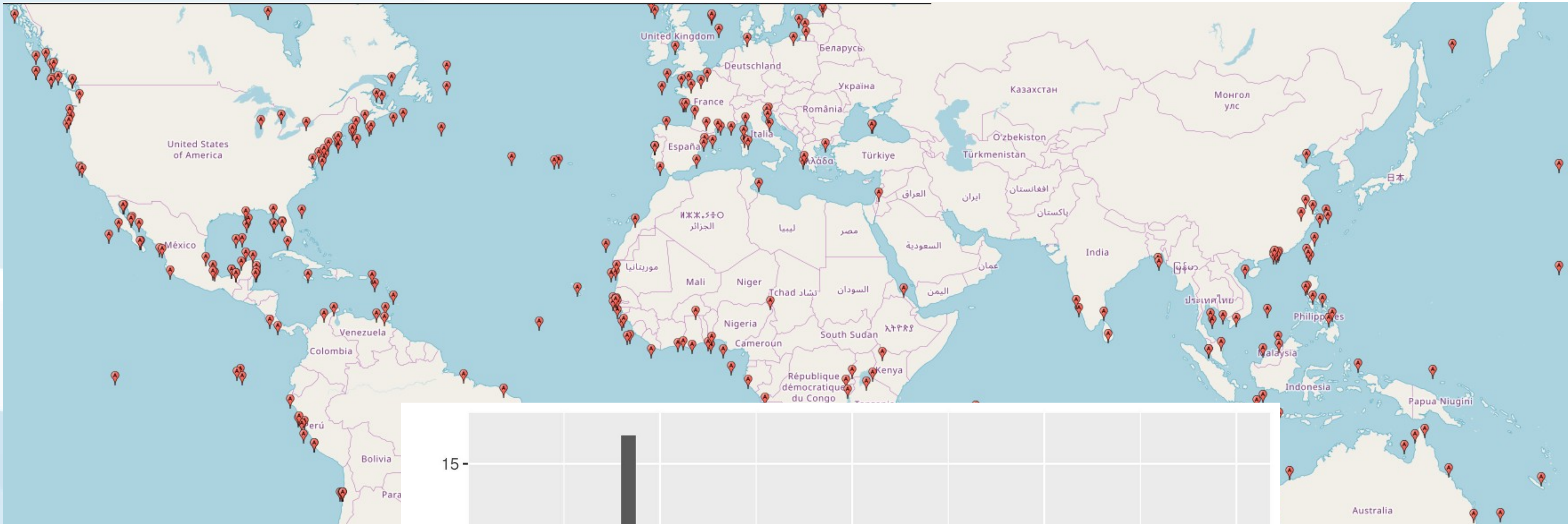
Weighted food webs

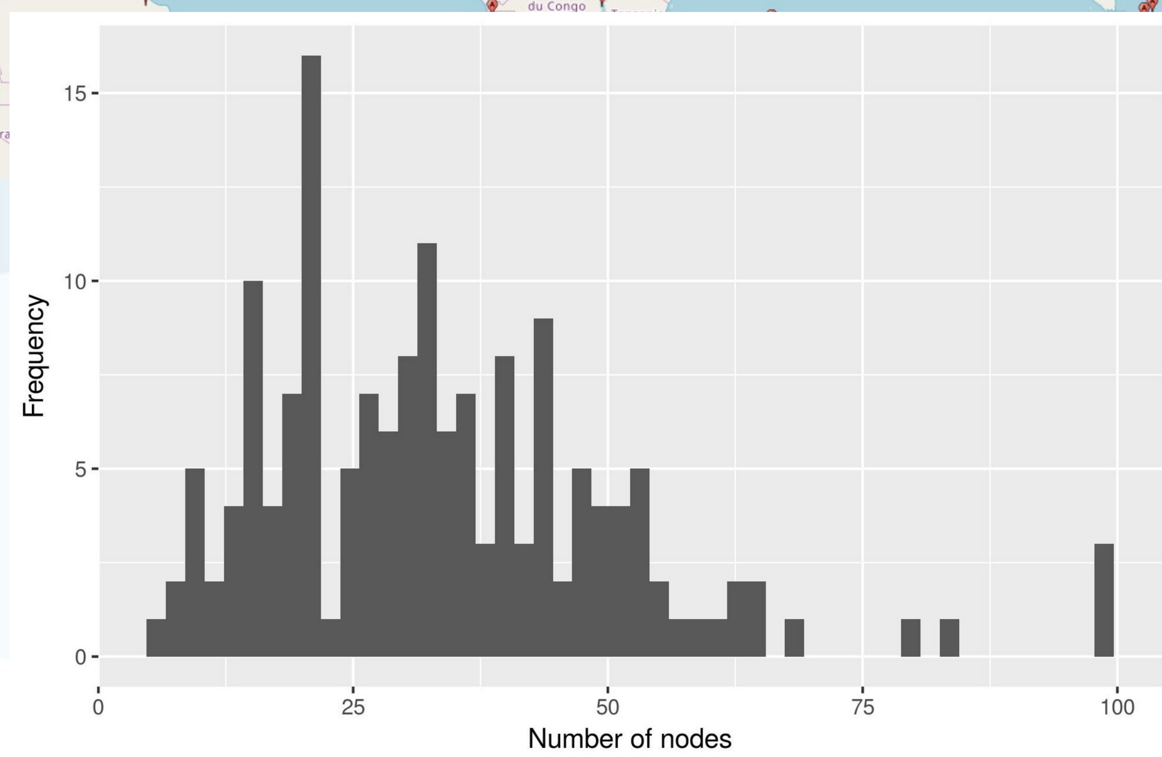
Dunne J.A. et al. (2002).
Food-web structure and network theory
PNAS 99 (20): 12917–12922

Systematic study of relations among multiple structural and vulnerability indicators

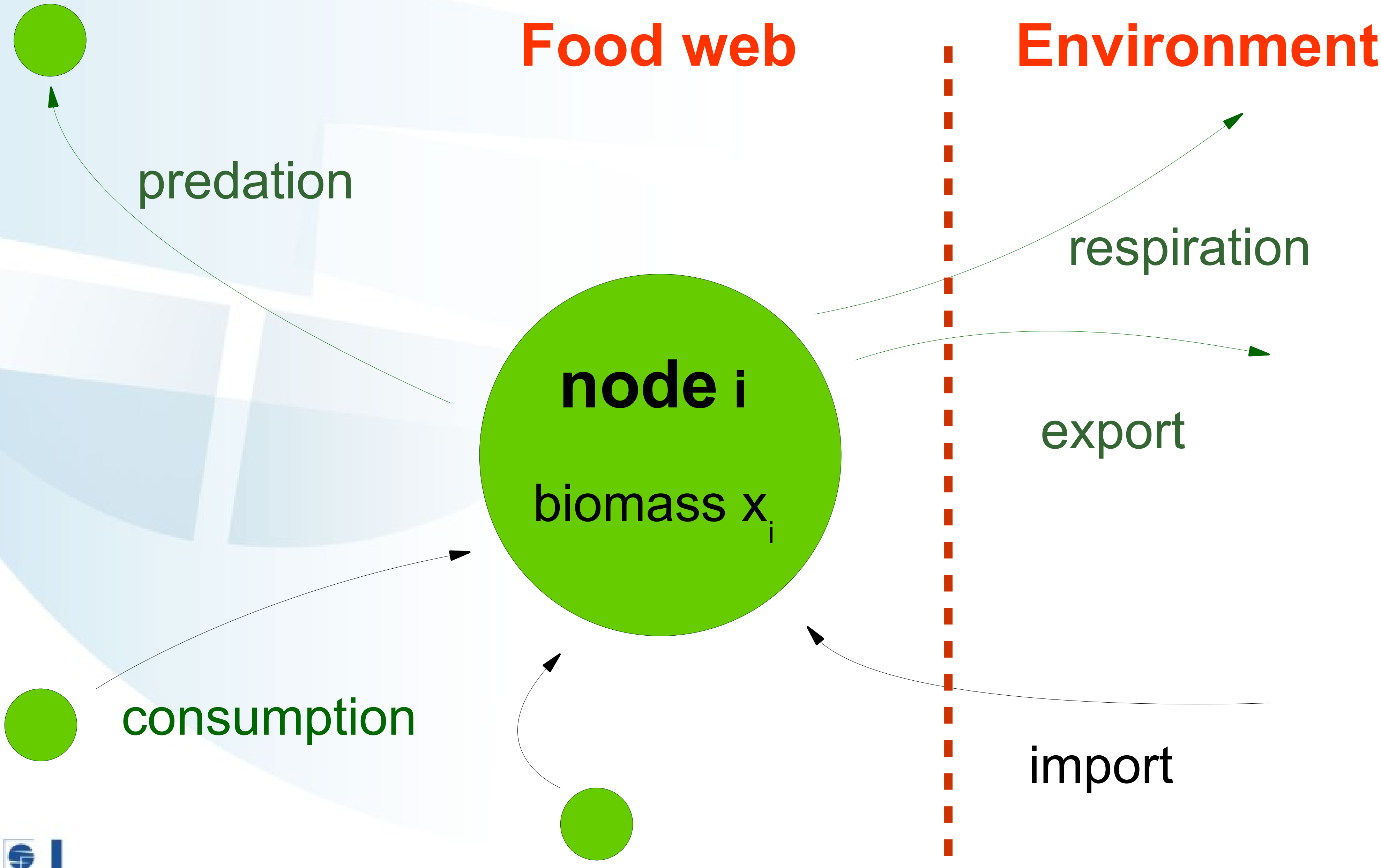
This talk

Data of 245 weighted food webs from different continents and ecosystems

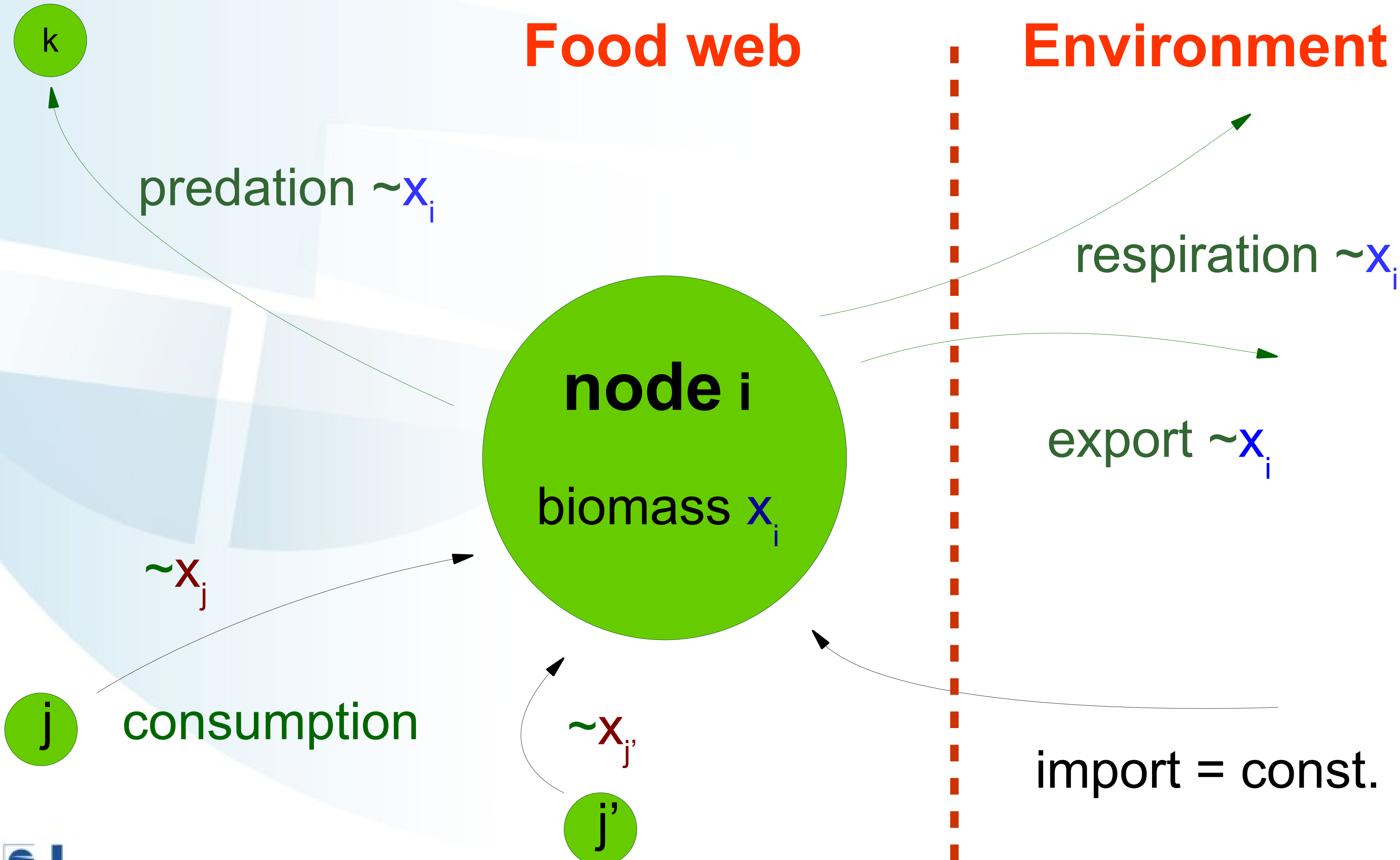




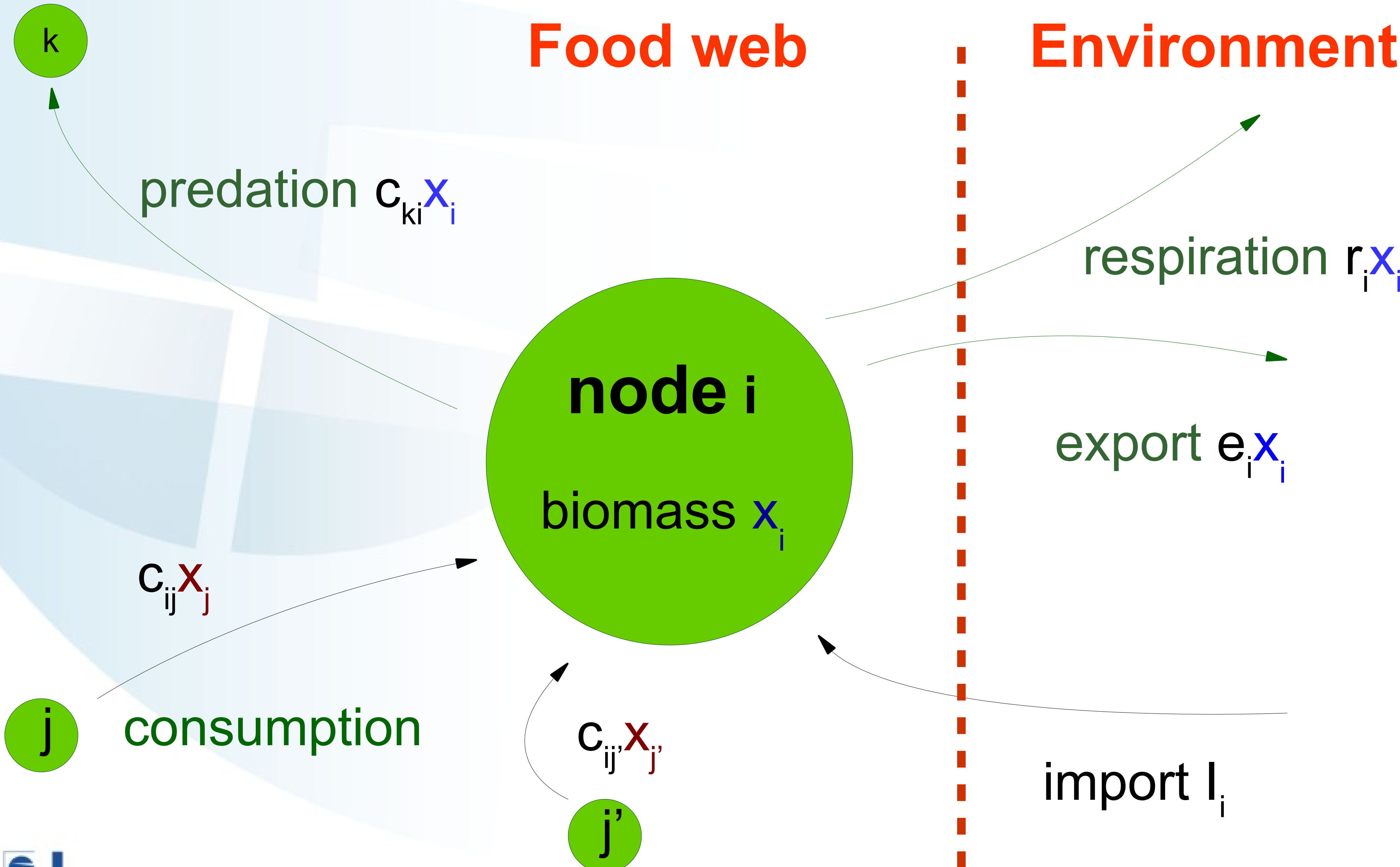
Data: steady-state biomass flows



Biomass flow dynamics: donor-control



Parameters c_{ij}, r_i, e_i, I_i are determined from the empirical flows and biomasses.



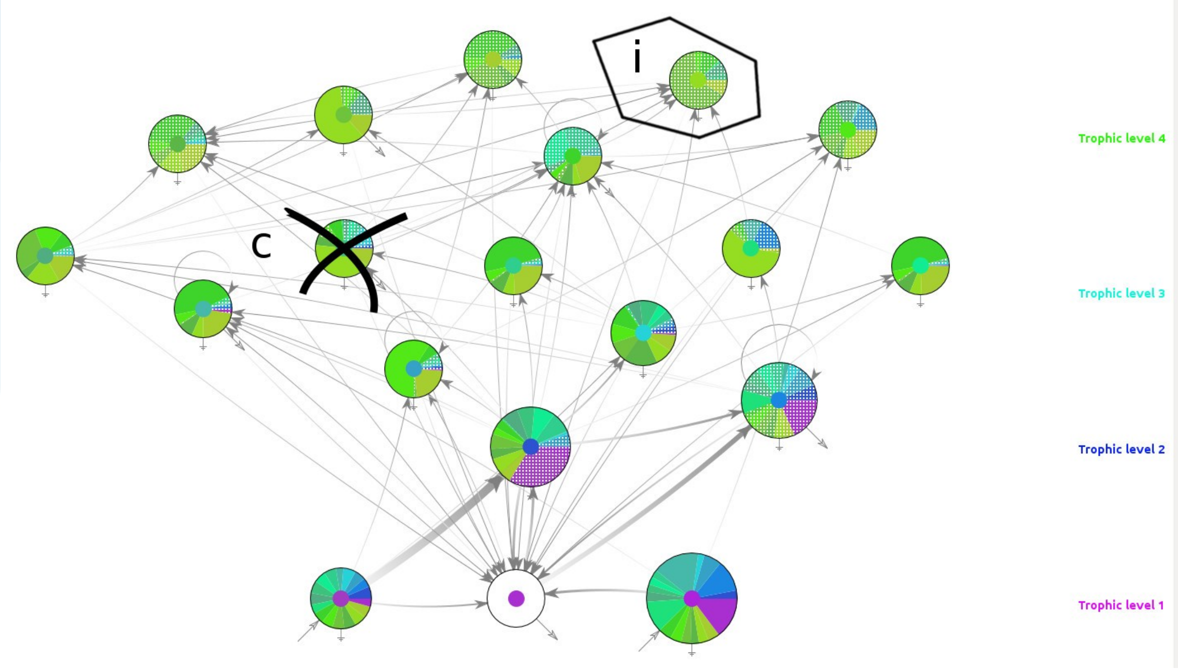
Simulation of node extinction

1. One node is removed.

2. Network evolves towards a new steady state:

$$\frac{d\vec{x}}{dt} = \text{inflows} - \text{outflows} = \boldsymbol{A}(\boldsymbol{C}, \vec{e}, \vec{r})\vec{x} + \vec{I}$$

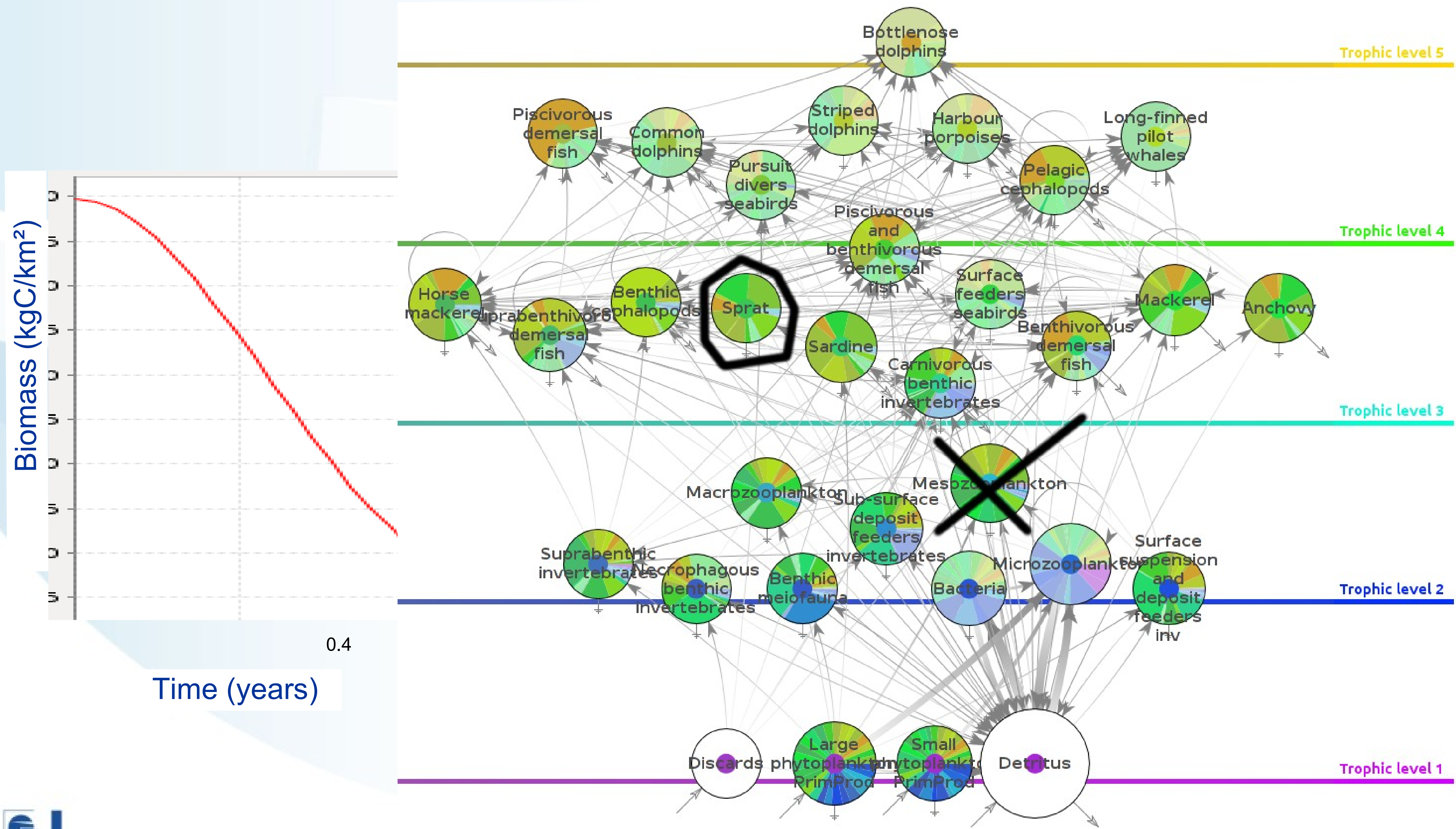
3. Impacts on the remaining nodes are analysed.



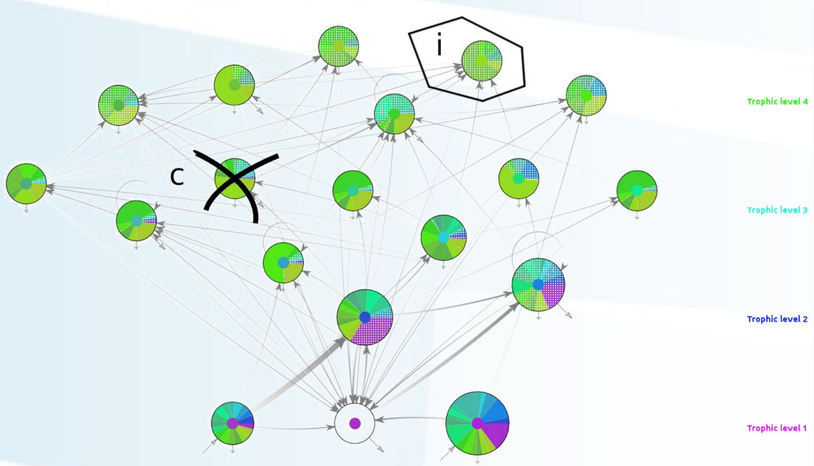
(Alaska, Prince William Sound)

Simulation example: Bay of Biscay

Sprat collapsing after Mesozooplankton has died



Extinction impact indicators



Final biomass of impacted node i after node c collapsed

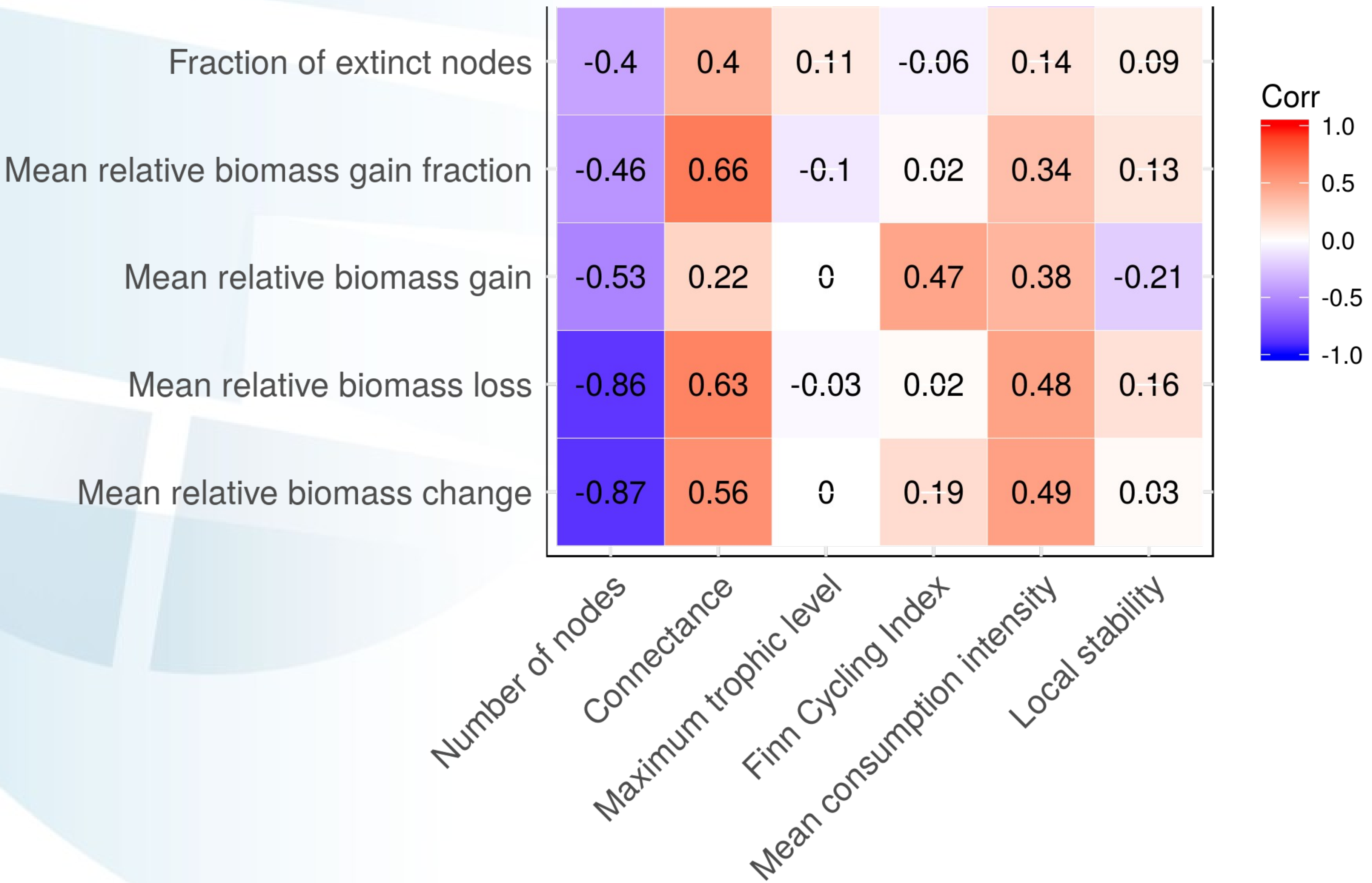
$$\delta_{ic} = \frac{|x_i^c - x_i|}{x_i}$$

Initial biomass of impacted node i

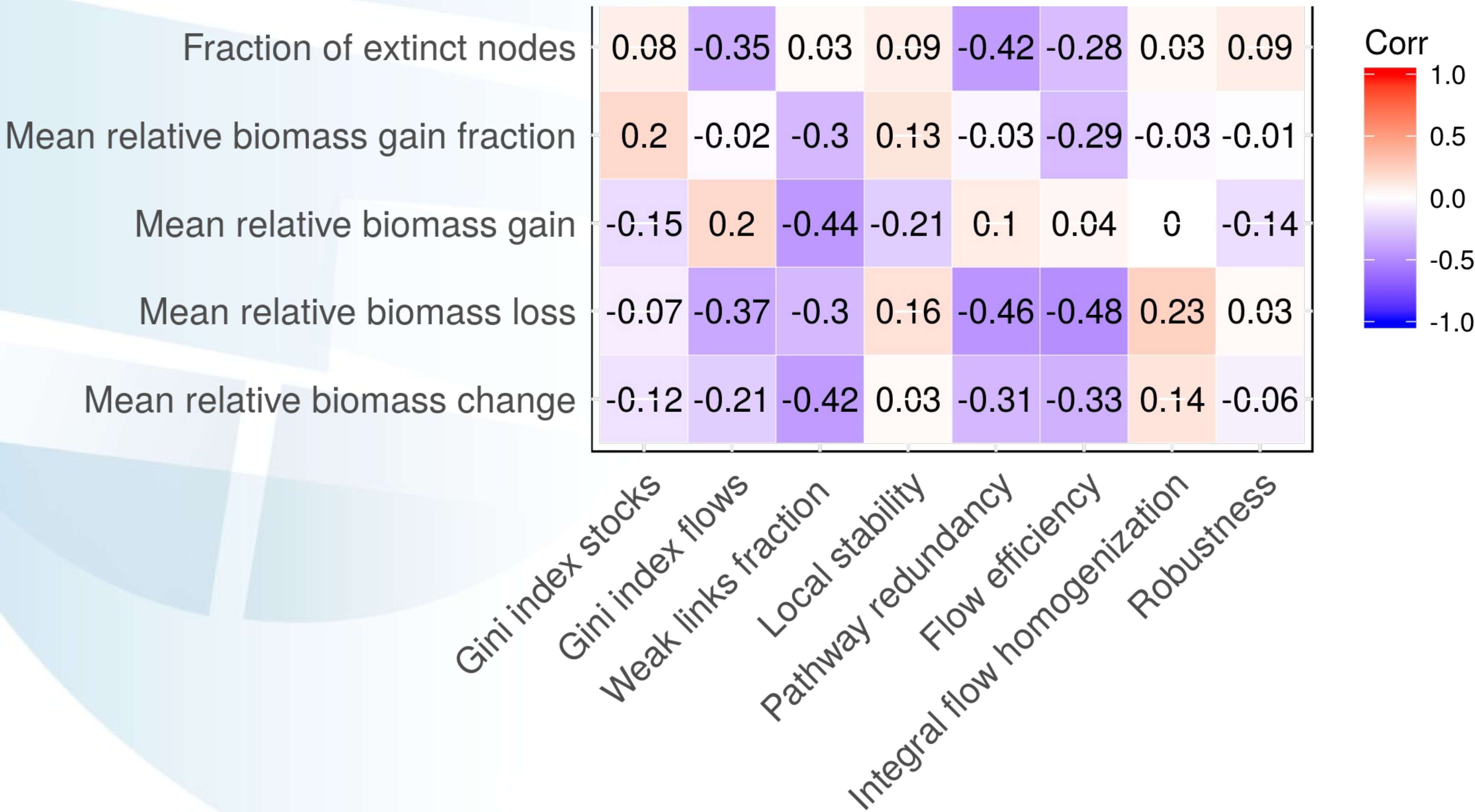
Mean relative biomass change in a network:

$$\delta_{\langle..\rangle} = \frac{1}{n_{\text{liv}}(n_{\text{liv}} - 1)} \sum_{c=1}^{n_{\text{liv}}} \sum_{i \neq c}^{n_{\text{liv}}} \delta_{ic}$$

Spearman correlations: general structure

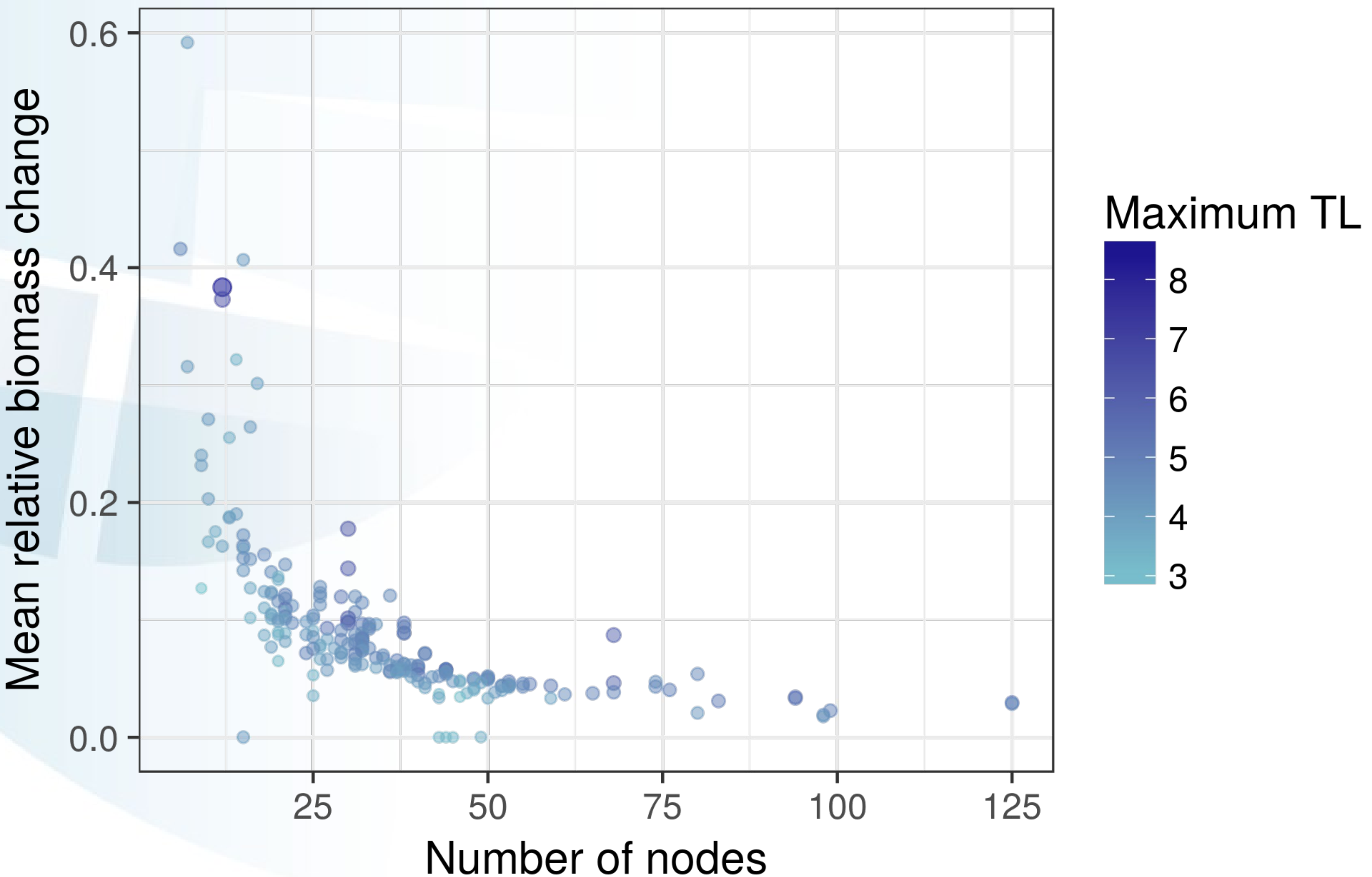


Spearman correlations: distributions



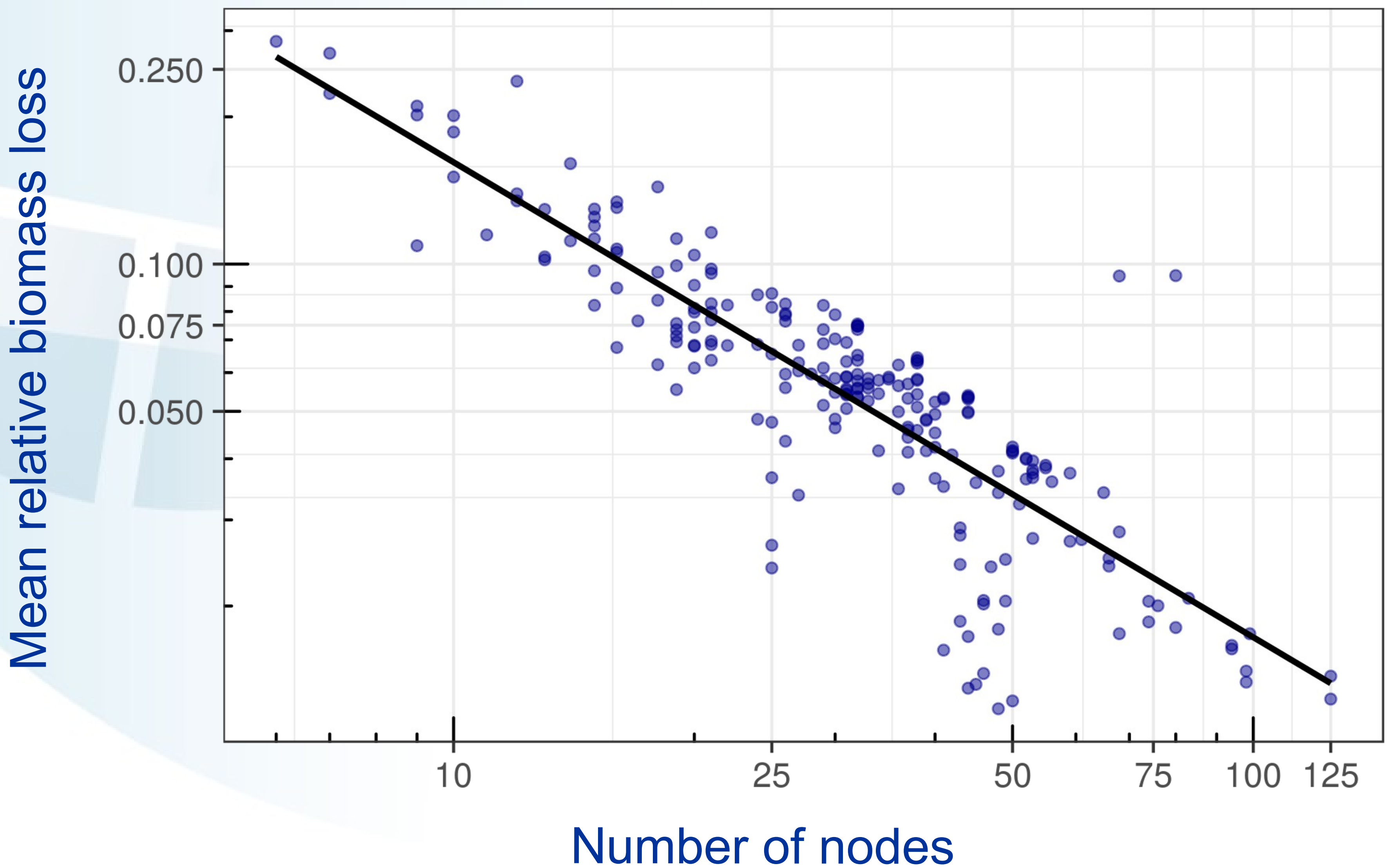
Size

Small food webs are more vulnerable to indirect impacts of species extinctions.



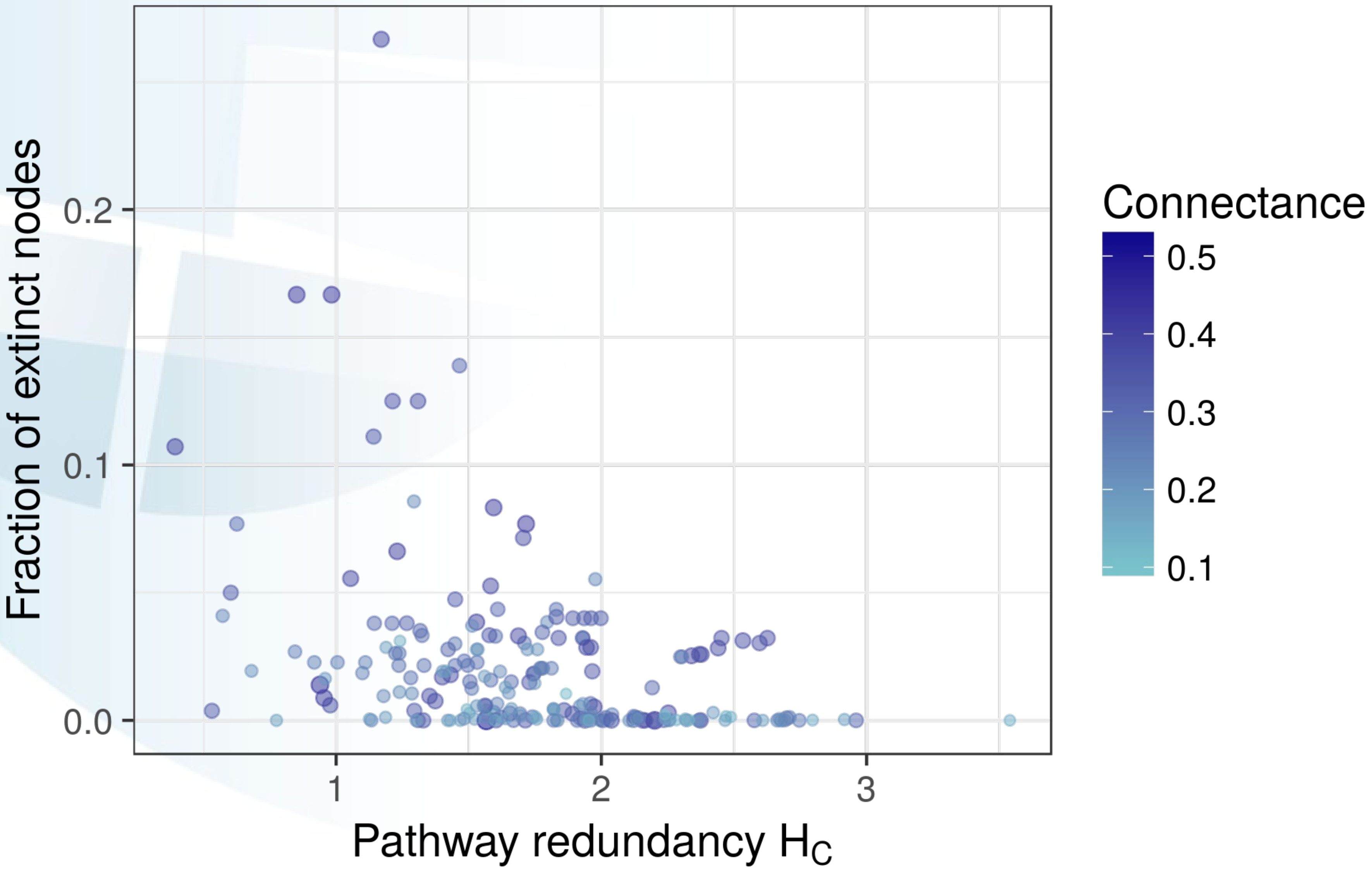
Relative loss ~ $n^{-1.03\pm0.04}$

The mean relative biomass loss is **inversely proportional** to the **number of nodes**.



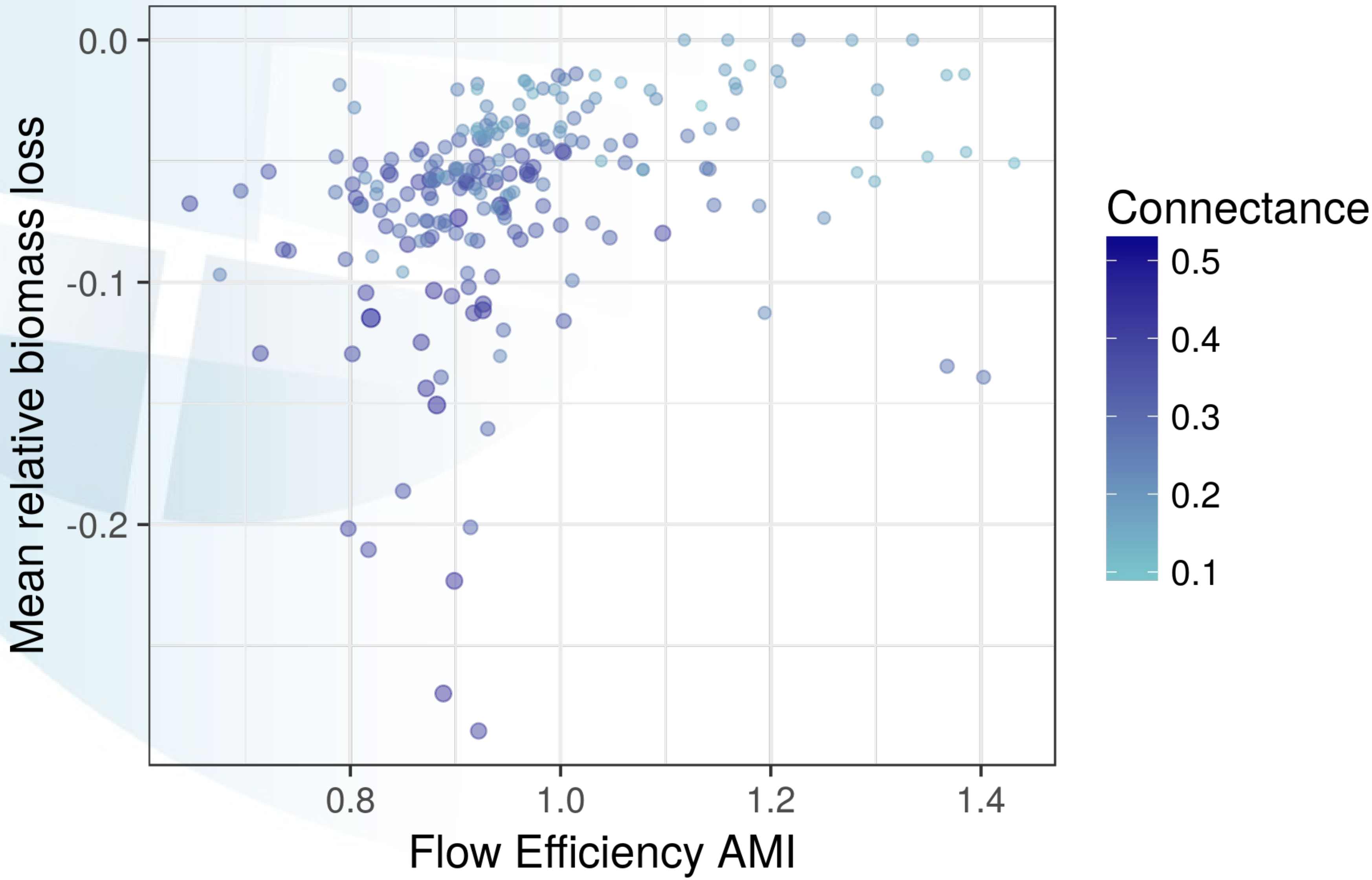
Flow distributions

The fraction of **secondary extinctions** is reduced in food webs with **more alternative pathways**.



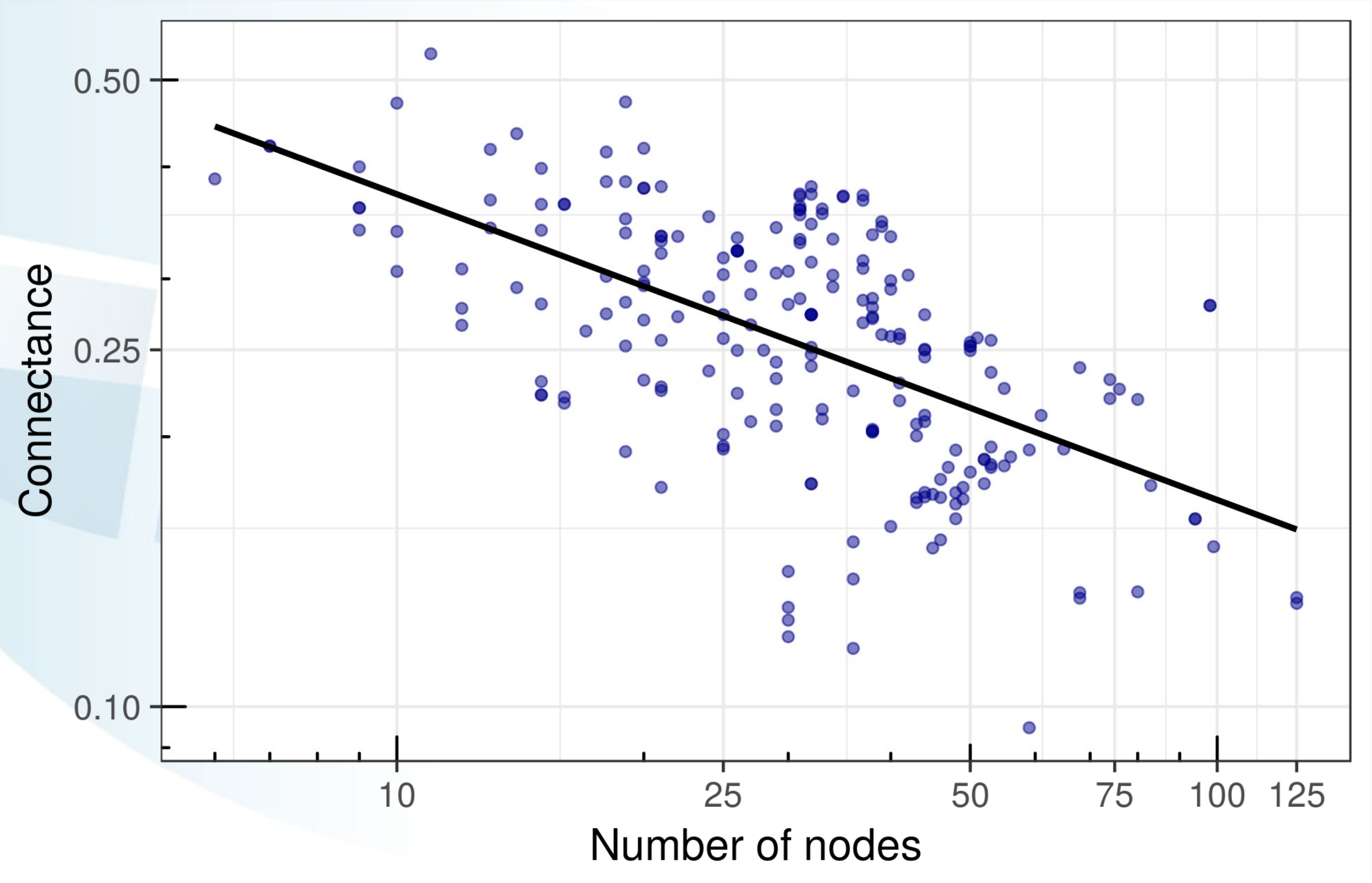
Flow distributions

The average relative biomass **loss** of a node is reduced in food webs with **more uneven flow distributions**.



Connectance ~ $n^{-0.37\pm0.03}$

Connectance follows a **power law** as a function of the **number of nodes**.



Multivariate regression with model selection

$$y_i = \frac{c}{n} + b_0 + b_1 x_1 + \ldots + b_n x_n + \epsilon_i$$

Vulnerability indicator

Structural measures

Model selection was done in two steps:

1. Iterative removal of the most strongly multicollinear variable (up to the VIF threshold 10).

3. Backward model selection using the Akaike criterion (AIC)r of nodes.

Regression – mean relative loss

$$y_i = \frac{c}{n} + b_0 + b_1 x_1 + ... + b_n x_n + \epsilon_i$$

Variables **reducing** losses w.r.t. baseline:

- Cycling of biomass (FCI)
- Flow Homogenization
- Local Stability measure
- Mean donor dependence

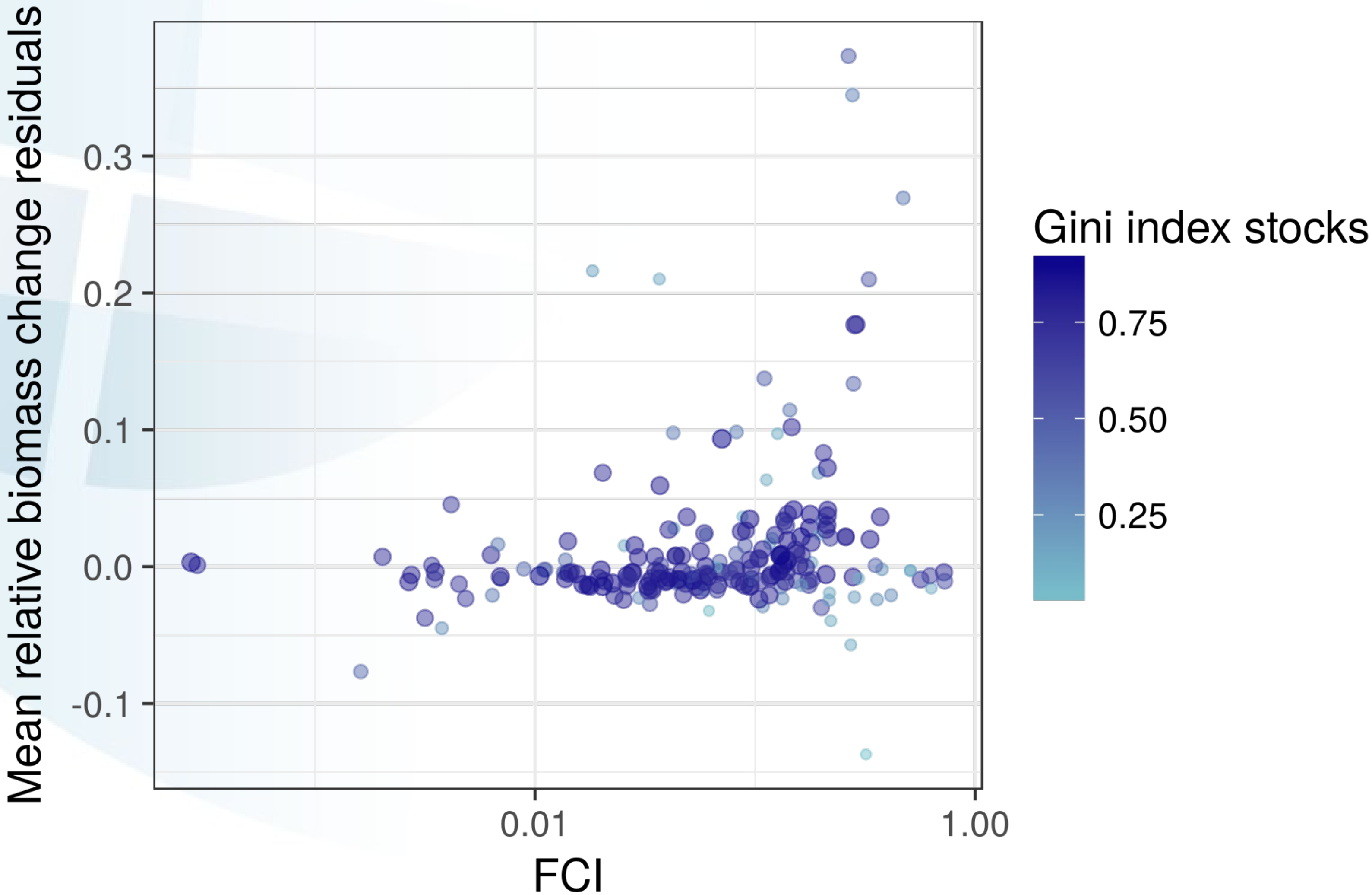
Variables **increasing** losses w.r.t. baseline:

- Flow efficiency (AMI)
- Weak links fraction
- Stock inequality
- Maximum trophic level
- Nestedness

Regression – mean relative change

$$y_i = \frac{c}{n} + b_0 + b_1 x_1 + \ldots + b_n x_n + \epsilon_i$$

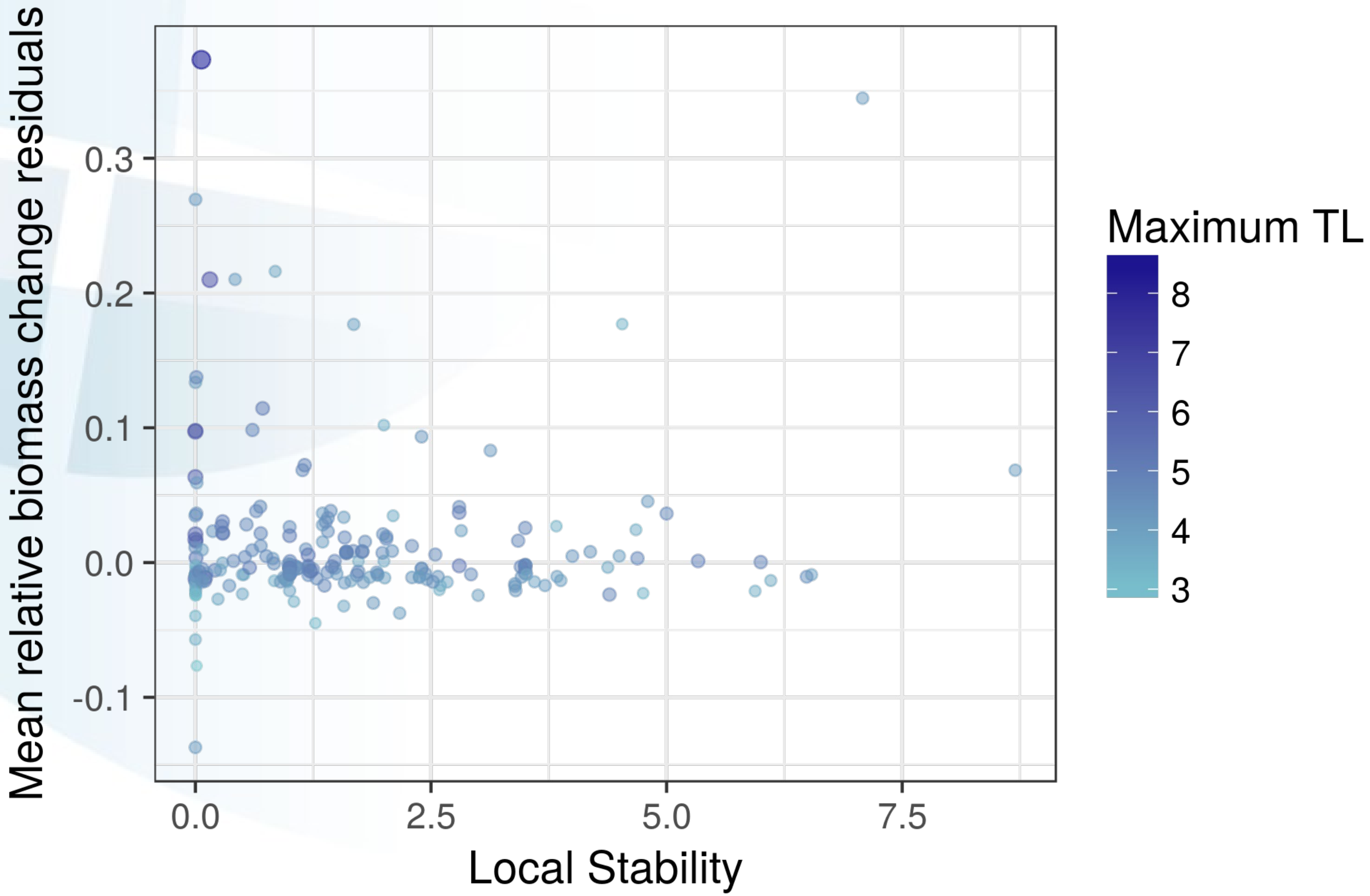
Higher **cycling** of biomass and higher **biomass stock inequality** increase vulnerability.



Regression – mean relative change

$$y_i = \frac{c}{n} + b_0 + b_1 x_1 + \ldots + b_n x_n + \epsilon_i$$

Enhanced **local stability** (Jacquet et al.) **reduces** also the impacts of large perturbations, while the **maximum trophic level increases** them.



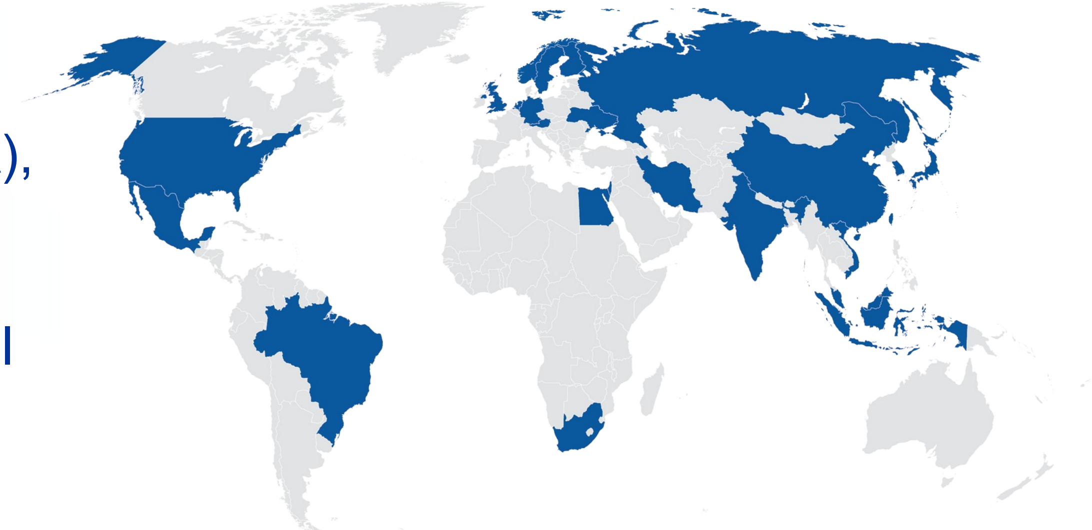
Summary and Outlook

- This analysis of a large ensemble of food webs across the world yields visible patterns in extinction impacts.
- **Small** and **highly connected** food webs are more vulnerable to indirect impacts of species extinctions.
- The average relative biomass change of a food-web node follows a power law as a function of the **number of nodes**.
- The average relative biomass loss of a node is reduced in food webs with **more uneven flow distributions**.

The project

IIASA

The International Institute for Applied Systems Analysis (IIASA), located in Laxenburg (Vienna), Austria,
conducts research into the critical issues of global environmental, economic, technological, and social change that we face in the twenty-first century.



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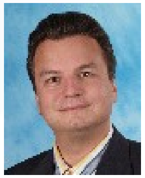

Ulf Dieckmann

Ursula Scharler

Åke Brännström

IBS PAN Systems Research Institute
Polish Academy of Sciences

Victoria Veshchynskaia

MI

Karol Opara

Thank You!

Questions?