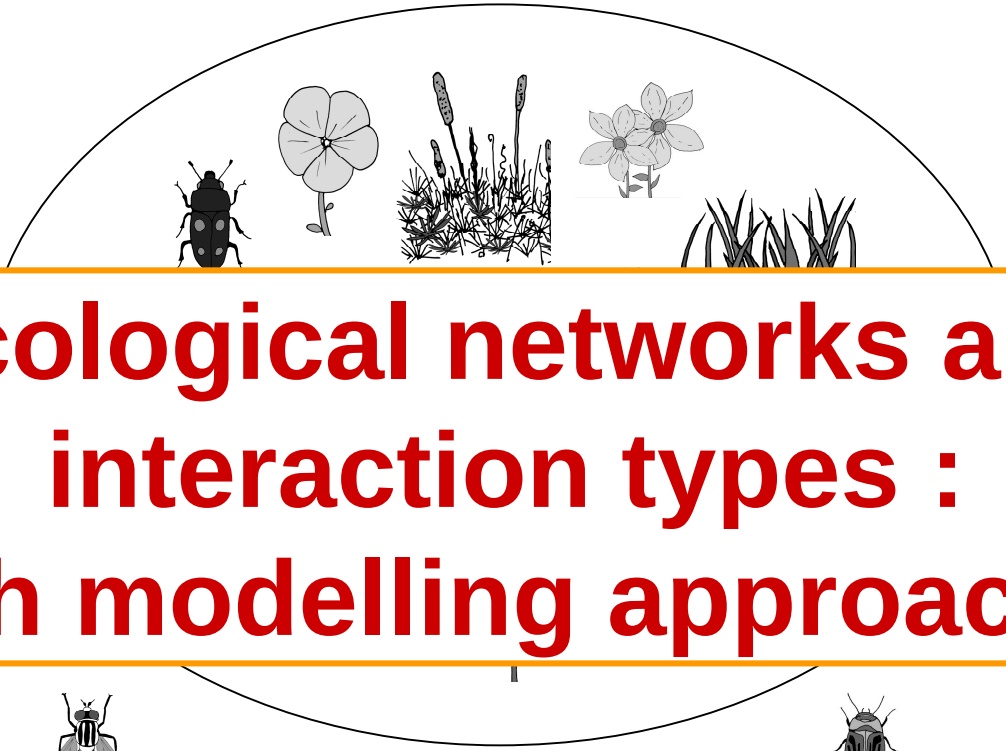
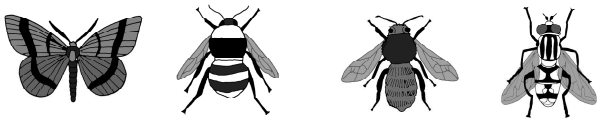


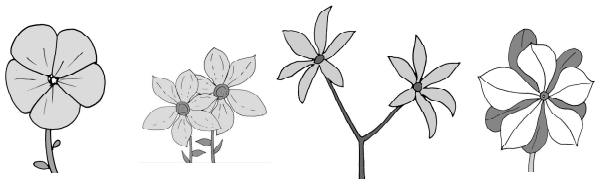
Ecological networks and interaction types : which modelling approaches?



Elisa Thébault

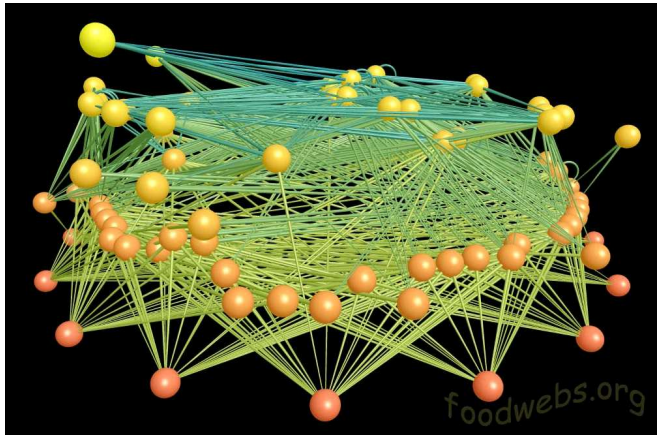
Mutualistic interactions

Trophic interactions



Wageningen University, The Netherlands

interaction networks



Modelling the dynamics of interaction networks

From May's work …

Dynamic of a *n* species community near equilibrium:

$$\frac{dx_i}{dt} = \sum_{j=1}^{n} a_{ij} x_j$$

with a_{ij} the effect of species *j* upon species *i* near equilibrium

		Effect of species *j* on *i* (i.e., sign of a_{ij})		
		+	0	−
Effect of species *i* on *j* (i.e., sign of a_{ji})	+	++	+0	+−
	0	0+	00	0−
	−	−+	−0	−−

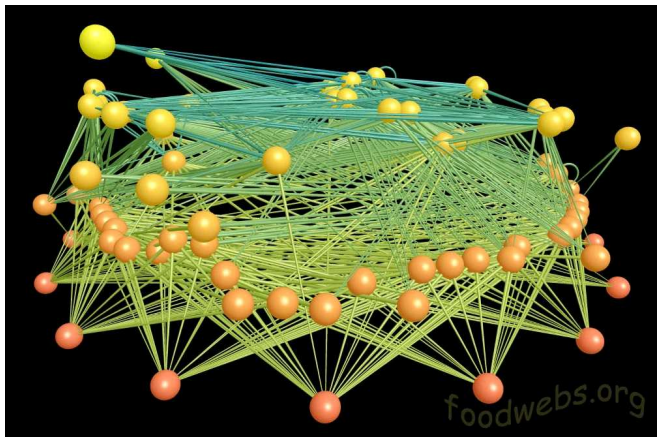
Apart from complete independence, there are five distinguishably different categories of interaction between any given pair of species, namely commensalism (+0), amensalism (−0) mutualism or symbiosis (++), competition (−−), and general predator-prey (+−) including plant-herbivore, parasite-host, and so on.

Stable if $s(nC)^{0.5}<1$

s interaction strength
C network connectance

May 1973

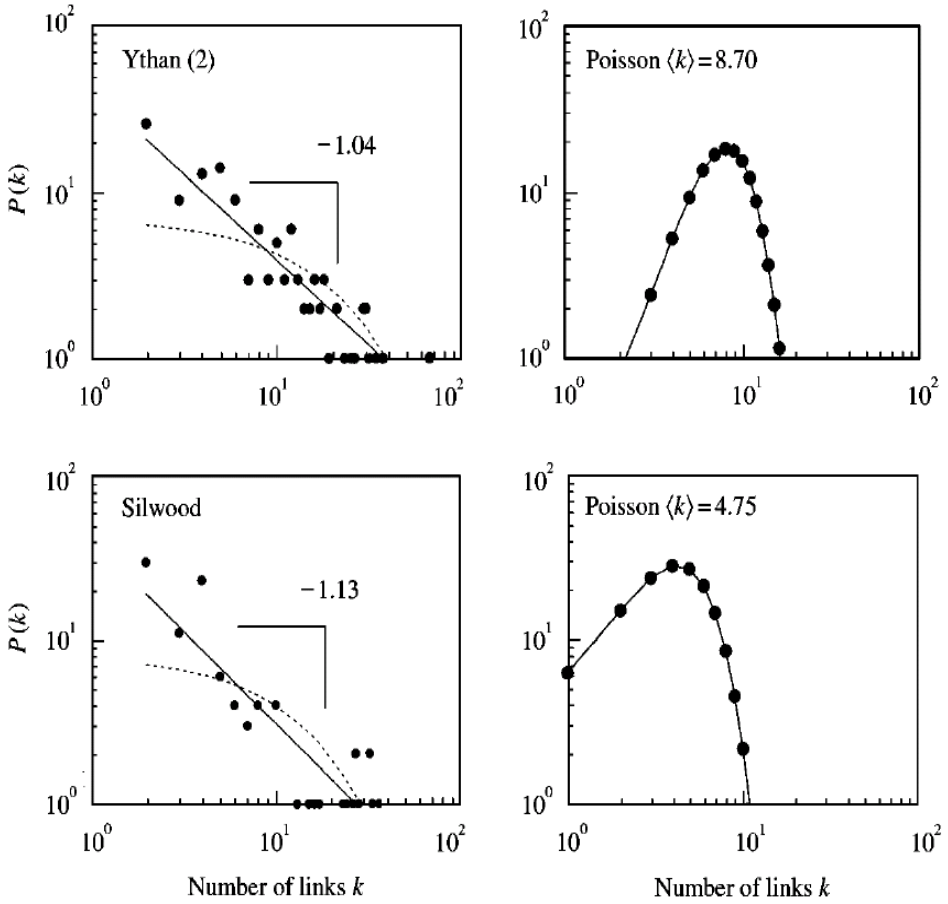
Modelling the dynamics of interaction networks



non random
structural patterns

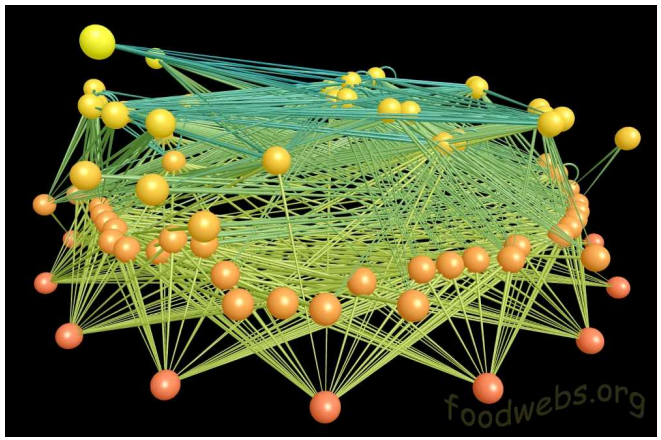
… to now

empirical data | random expectation



Montoya & Solé (2002)

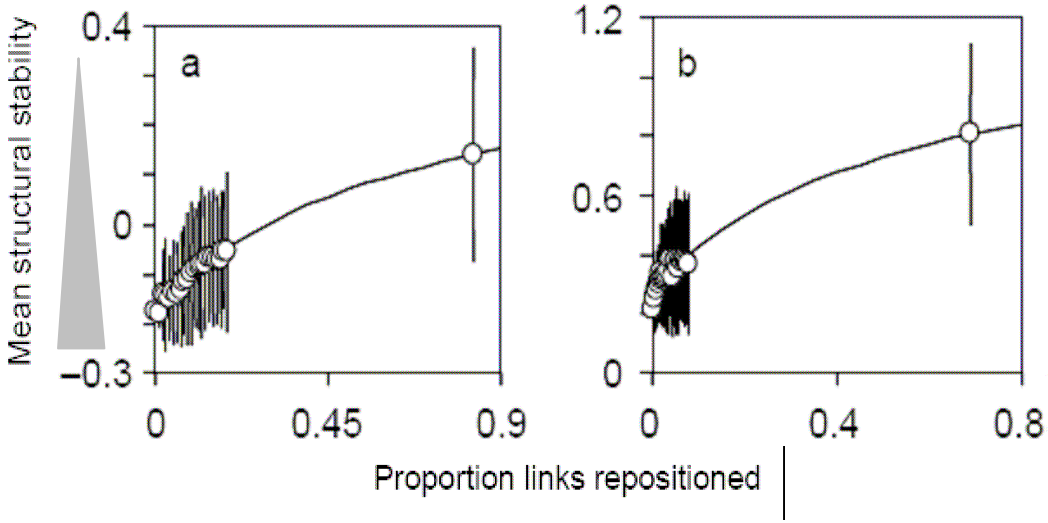
Modelling the dynamics of interaction networks



non random structural patterns

community stability

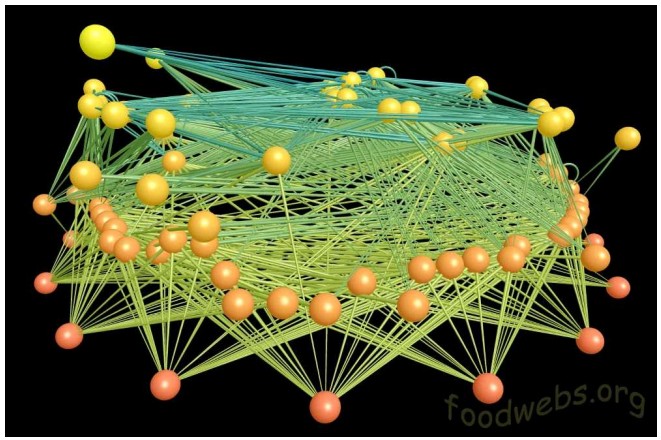
… to now



Non random structural patterns enhance community stability

Fox (2006)

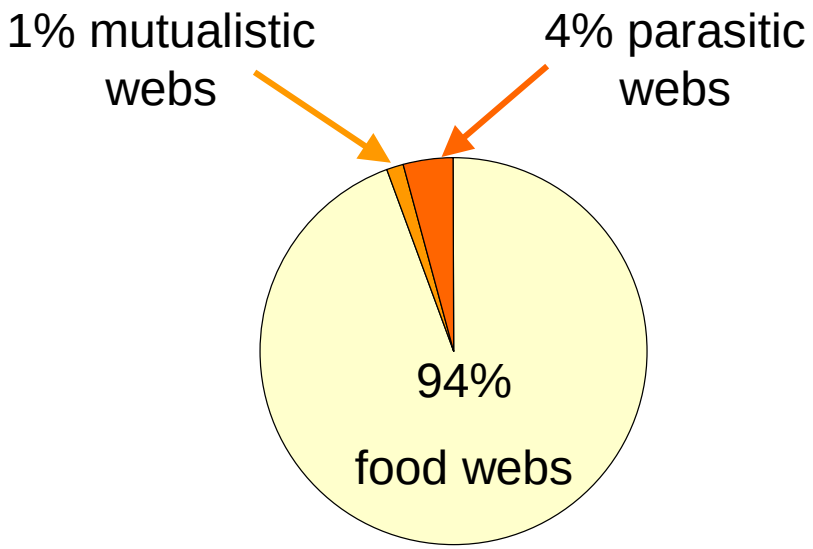
Modelling the dynamics of interaction networks



non random structural patterns

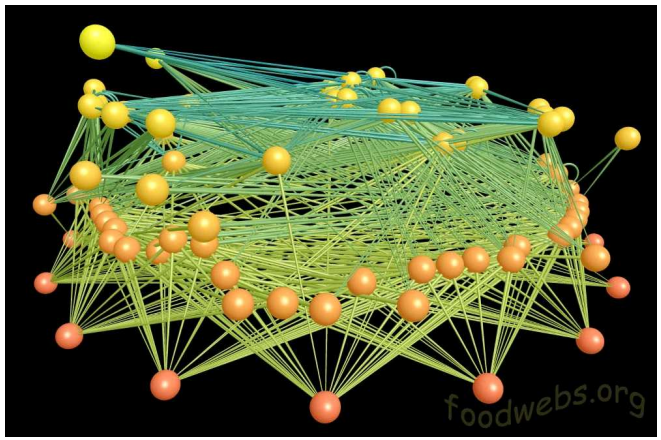
community stability

… to now



Proportions of papers on ecological networks published in the last 50 years that were related to food webs, mutualistic webs and parasitic webs

Modelling the dynamics of interaction networks



non random structural patterns

community stability

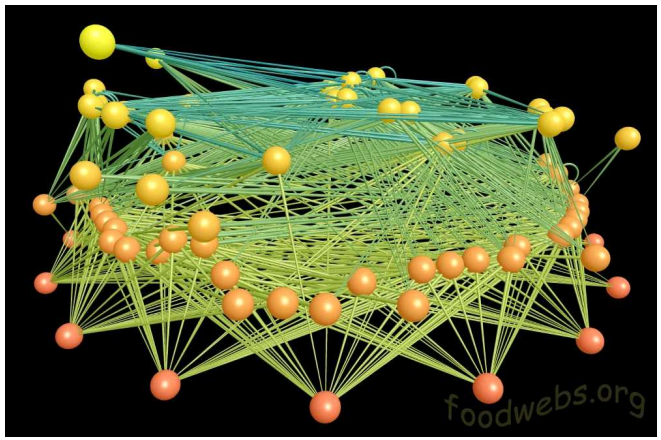
… to now

Food webs → Large number of analyses of food web models

Mutualistic webs → Only a few recent works

Host-parasite & host-parasitoid webs → No models at network level?

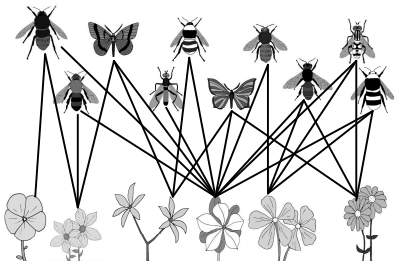
Modelling the dynamics of interaction networks



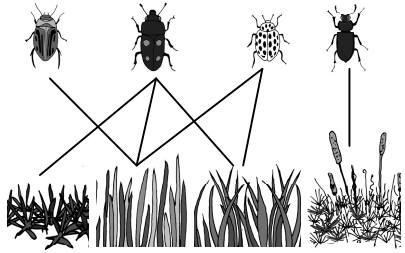
non random
structural patterns

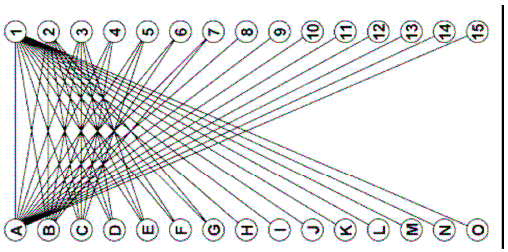
community stability

Mutualistic

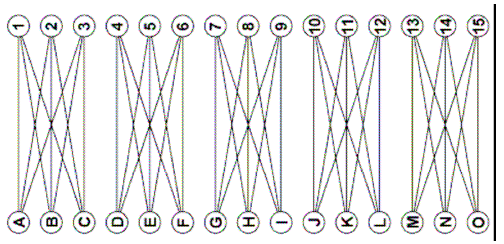


Trophic



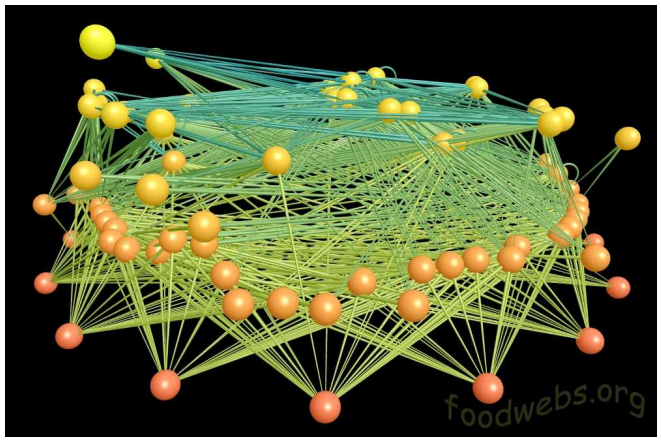


nested



compartmented

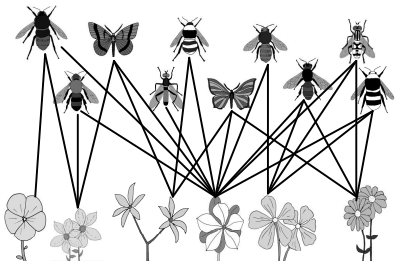
Modelling the dynamics of interaction networks



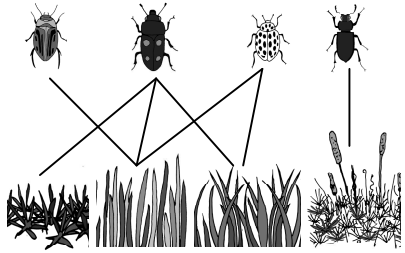
non random structural patterns

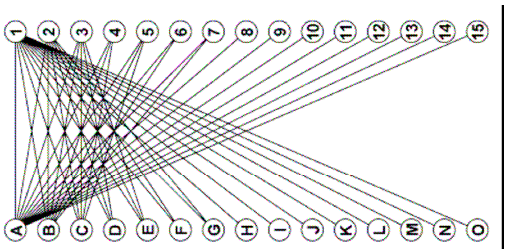
community stability

Mutualistic



Trophic





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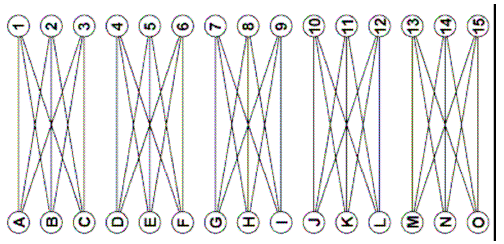
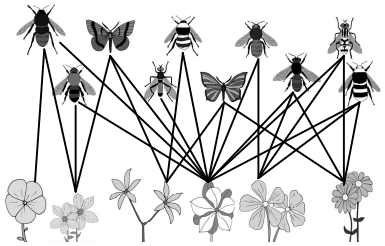


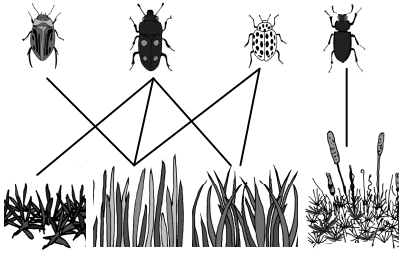
compartmented

How these different structures affect species coexistence and stability in both networks?

The model: dynamics of mutualistic and trophic webs



Mutualistic



Trophic

$$\frac{dA_i}{dt} = r_{Ai}A_i - I_{Ai}A_i^2 + \sum_{j=1}^{Np} \frac{c_{ji}A_iP_j}{\alpha_{ji}^{-1} + \sum_{Pk \in mut(Ai)} P_k}$$

$$\frac{dP_i}{dt} = r_{Pi}P_i - I_{Pi}P_i^2 + \sum_{j=1}^{Na} \frac{c_{ij}A_jP_i}{\alpha_{ij}^{-1} + \sum_{Ak \in mut(Pi)} A_k}$$

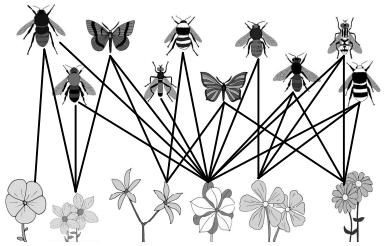
$$\frac{dA_i}{dt} = r_{Ai}A_i - I_{Ai}A_i^2 + \sum_{j=1}^{Np} \frac{c_{ji}A_iP_j}{\alpha_{ji}^{-1} + \sum_{Pk \in prey(Ai)} P_k}$$

$$\frac{dP_i}{dt} = r_{Pi}P_i - I_{Pi}P_i^2 - \sum_{j=1}^{Na} \frac{c_{ij}A_jP_i}{\alpha_{ij}^{-1} + \sum_{Pk \in prey(Aj)} P_k}$$

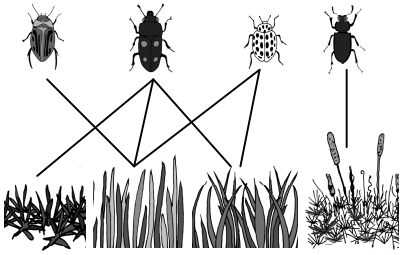
-intrinsic growth rates
r_P and $r_A < 0$ ➔ obligate mutualism

-intrinsic growth rates
$r_P > 0$ and $r_A < 0$

The model: dynamics of mutualistic and trophic webs



Mutualistic



Trophic

$$\frac{dA_i}{dt} = r_{Ai}A_i - l_{Ai}A_i^2 + \sum_{j=1}^{Np} \frac{c_{ji}A_iP_j}{\alpha_{ji}^{-1} + \sum_{Pk \in mut(Ai)} P_k}$$

$$\frac{dP_i}{dt} = r_{Pi}P_i - l_{Pi}P_i^2 + \sum_{j=1}^{Na} \frac{c_{ij}A_jP_i}{\alpha_{ij}^{-1} + \sum_{Ak \in mut(Pi)} A_k}$$

$$\frac{dA_i}{dt} = r_{Ai}A_i - l_{Ai}A_i^2 + \sum_{j=1}^{Np} \frac{c_{ji}A_iP_j}{\alpha_{ji}^{-1} + \sum_{Pk \in prey(Ai)} P_k}$$

$$\frac{dP_i}{dt} = r_{Pi}P_i - l_{Pi}P_i^2 - \sum_{j=1}^{Na} \frac{c_{ij}A_jP_i}{\alpha_{ij}^{-1} + \sum_{Pk \in prey(Aj)} P_k}$$

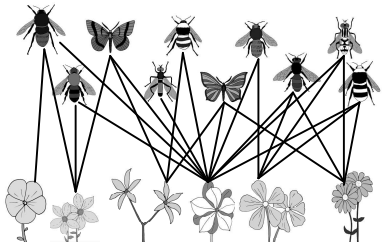
-intrinsic growth rates
r_P and $r_A < 0$ ➔ obligate mutualism

-density dependence term

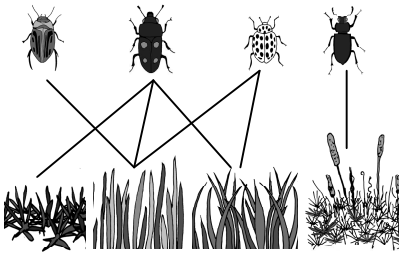
-intrinsic growth rates
$r_P > 0$ and $r_A < 0$

-density dependence term

The model: dynamics of mutualistic and trophic webs



Mutualistic



Trophic

$$\frac{dA_i}{dt} = r_{A_i}A_i - l_{A_i}A_i^2 + \frac{\sum_{j=1}^{N_P} c_{ij}A_i P_j}{h_{A_i} + \alpha_{A_i}A_i + \sum_{k=1}^{N_{P\,mut}(A_i)} \beta_{ik}P_k}$$

$$\frac{dP_i}{dt} = r_{P_i}P_i - l_{P_i}P_i^2 + \frac{\sum_{j=1}^{N_A} c_{ij}A_j P_i}{h_{P_i} + \alpha_{P_i}P_i + \sum_{k=1}^{N_{A\,mut}(P_i)} \beta_{ik}A_k}$$

-intrinsic growth rates
r_P and $r_A < 0$ ➔ obligate mutualism

-density dependence term

-interaction term
saturates with mutualistic partner densities

$$\frac{dA_i}{dt} = r_{A_i}A_i - l_{A_i}A_i^2 + \frac{\sum_{j=1}^{N_P} c_{ij}A_i P_j}{h_{A_i} + \alpha_{A_i}A_i + \sum_{k=1}^{N_{P\,prey}(A_i)} \beta_{ik}P_k}$$

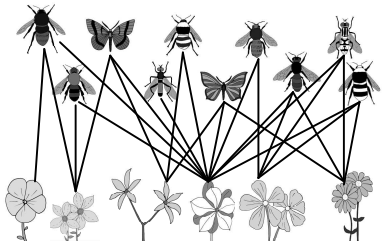
$$\frac{dP_i}{dt} = r_{P_i}P_i - l_{P_i}P_i^2 - \frac{\sum_{j=1}^{N_A} c_{ij}A_j P_i}{h_{P_i} + \alpha_{P_i}P_i + \sum_{k=1}^{N_{A\,prey}(P_i)} \beta_{ik}A_k}$$

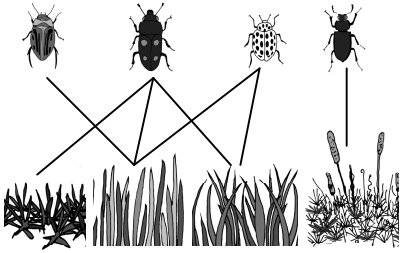
-intrinsic growth rates
$r_P > 0$ and $r_A < 0$

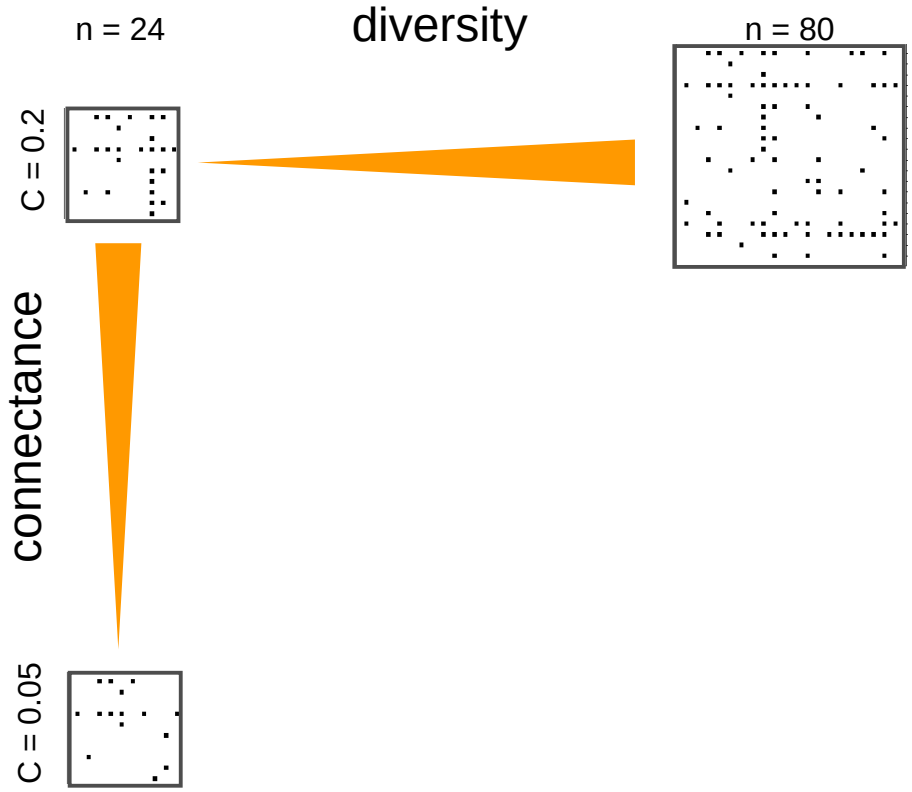
-density dependence term

-interaction term
saturates with prey densities

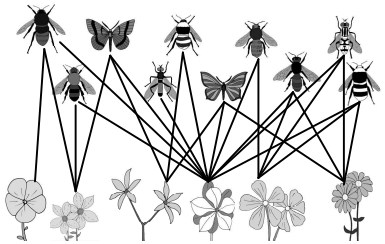
The model: network structure

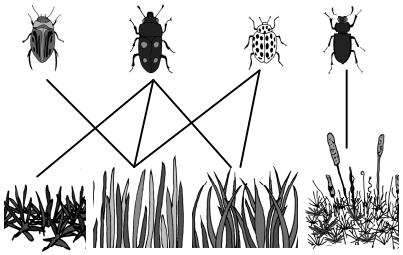


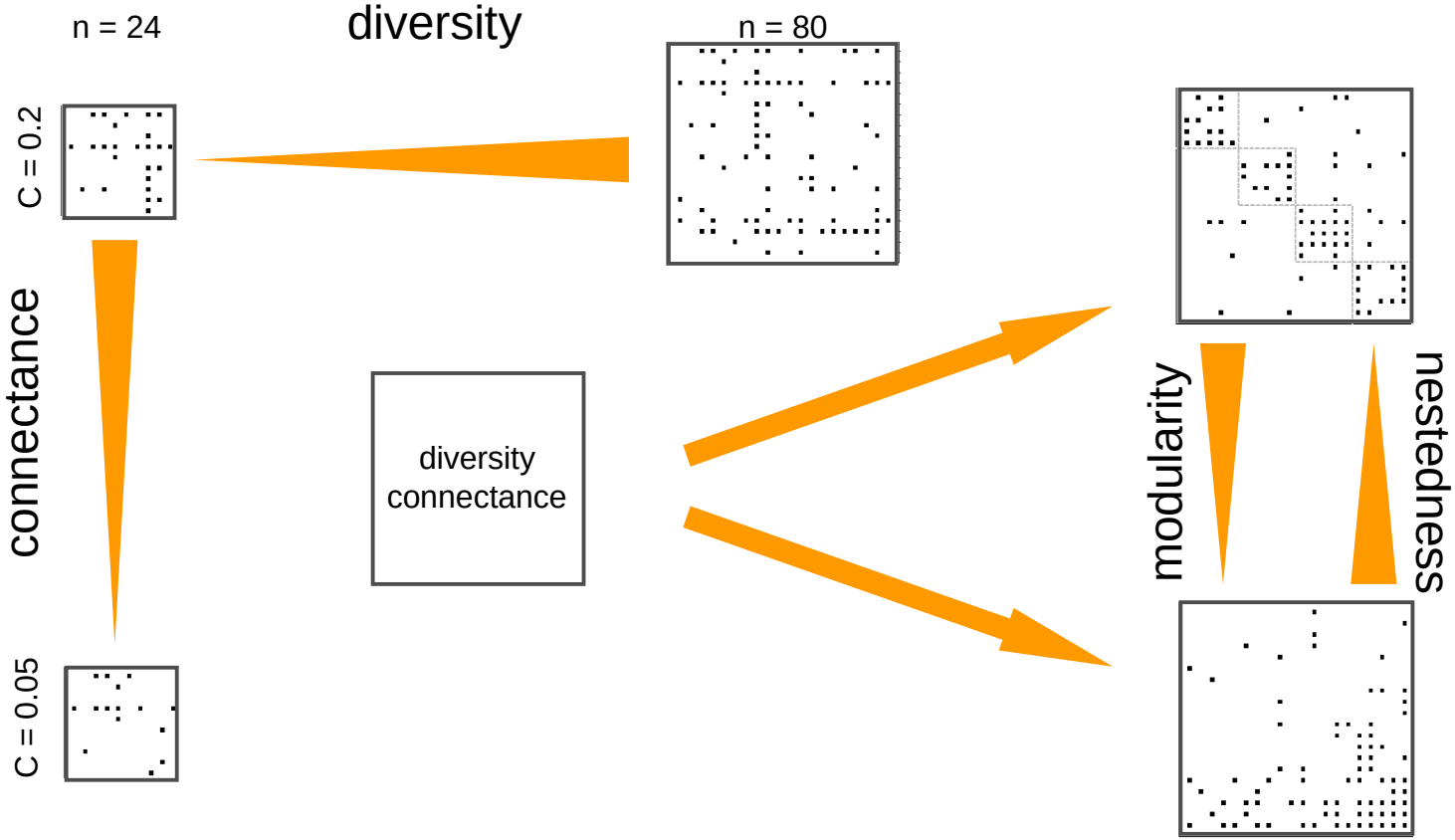




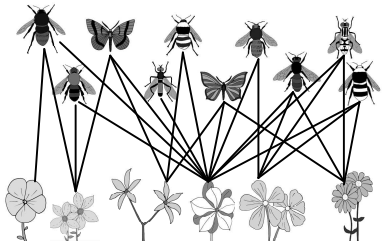
The model: network structure

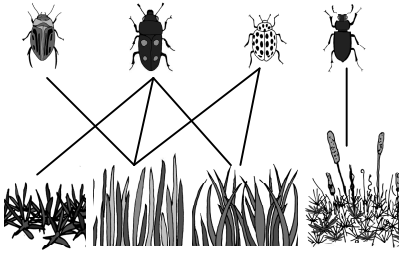


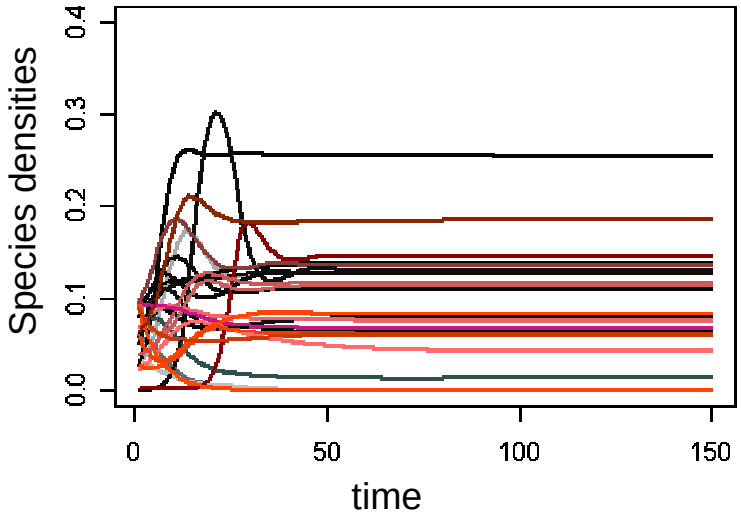




The model: stability measurements







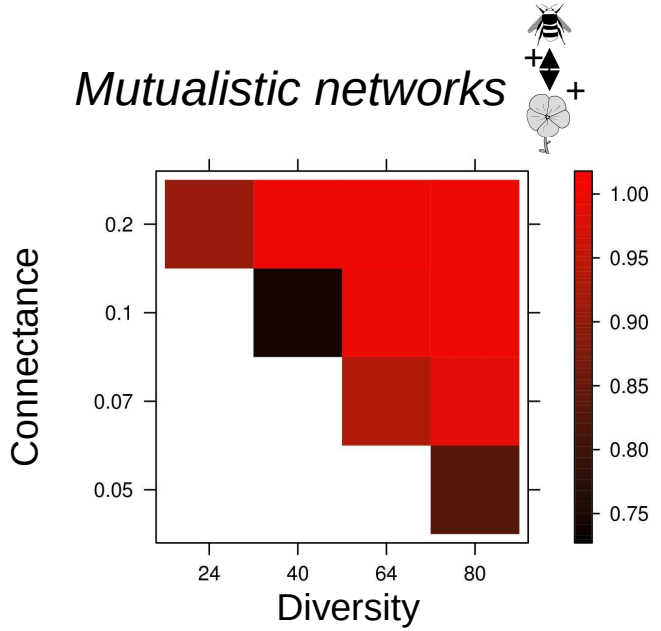
➢ Persistence:

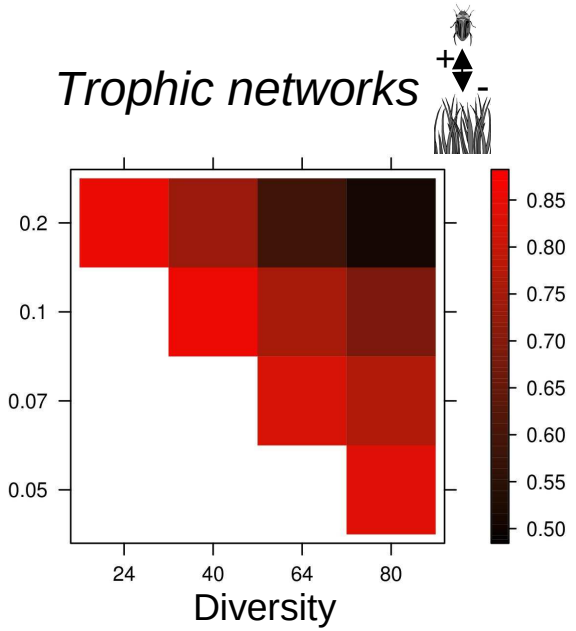
proportion of species persisting at equilibrium

➢ Resilience:

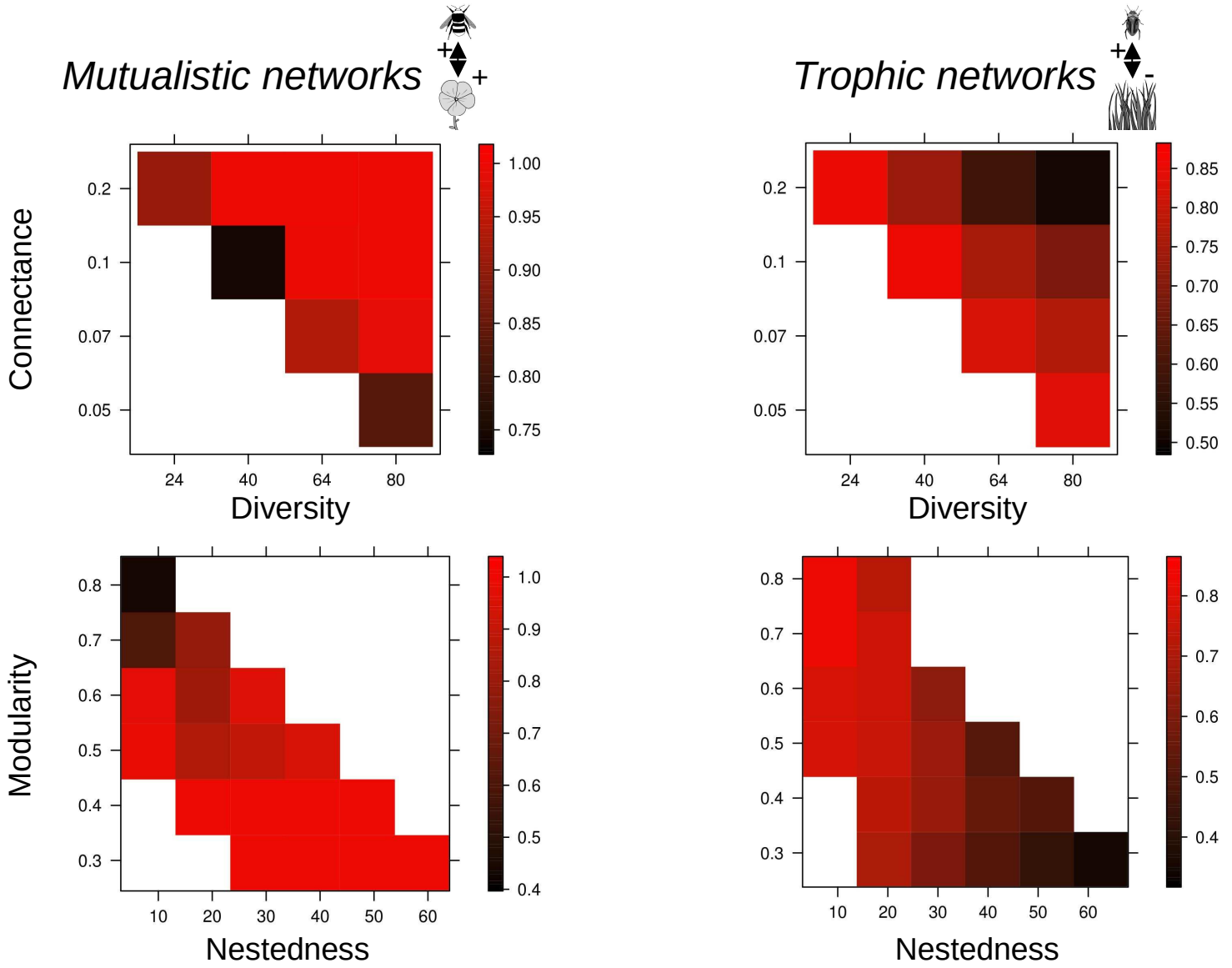
measure of the speed at which a system returns to its original state after a perturbation
Evaluated by the absolute value of the dominant eigenvalue of the Jacobian matrix of the system at equilibrium

Results: impact of network structure on persistence

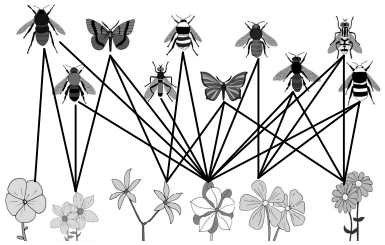




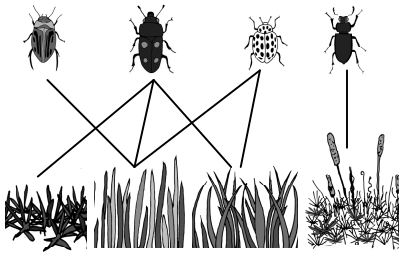
Results: impact of network structure on persistence



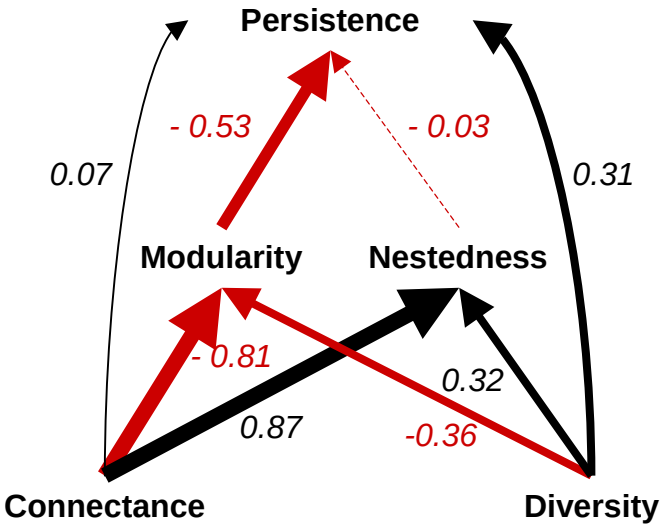
Results: impact of network structure on persistence

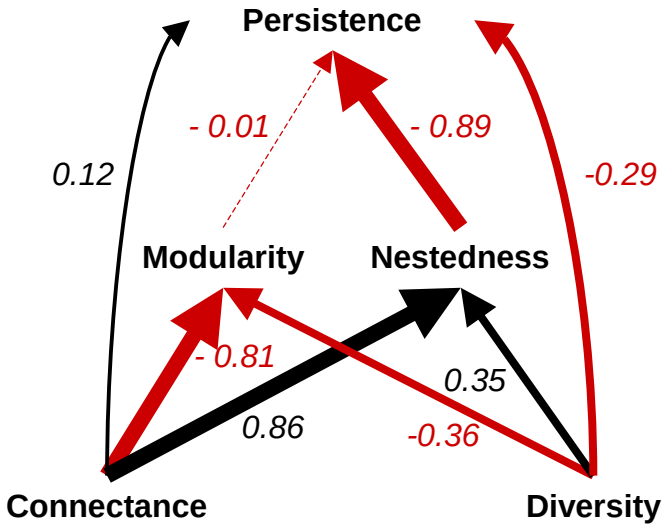


Mutualistic



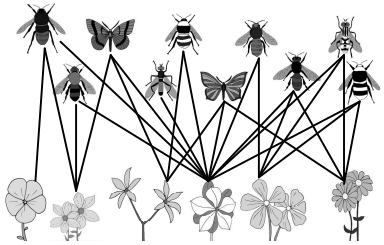
Trophic



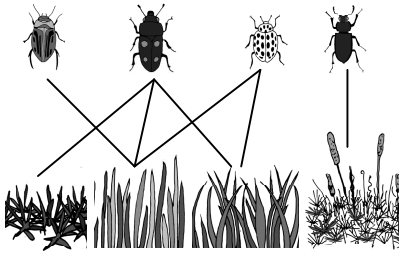


➢ opposite effect of network structure on the persistence of mutualistic and trophic networks

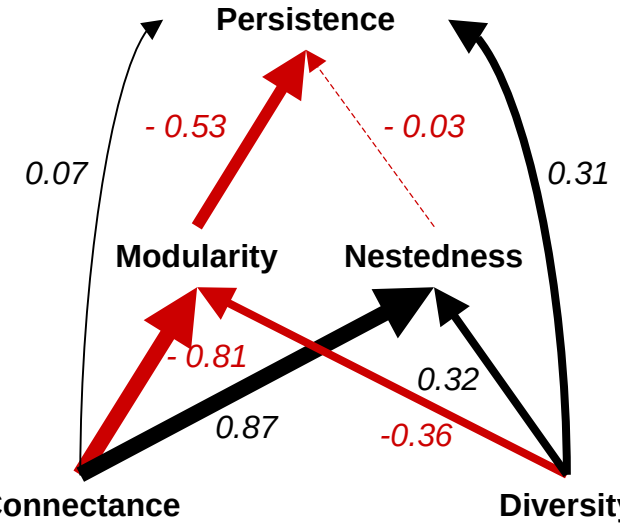
Results: impact of network structure on persistence



Mutualistic

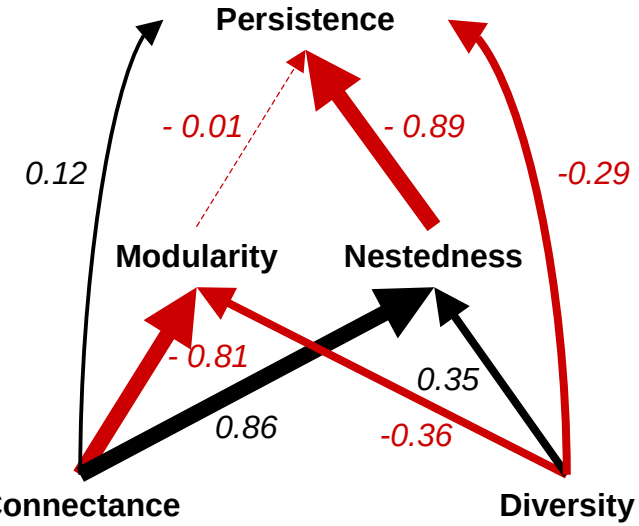


Trophic



indirect effect: 0.40

indirect effect: 0.18

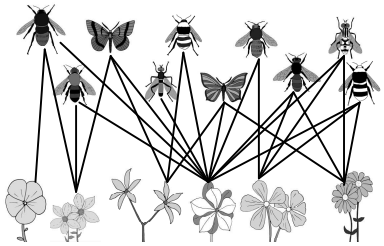


indirect effect: -0.76

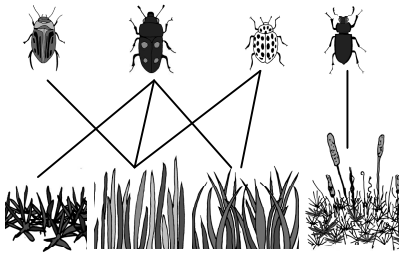
indirect effect: -0.31

➢ Importance of nestedness and modularity for network stability

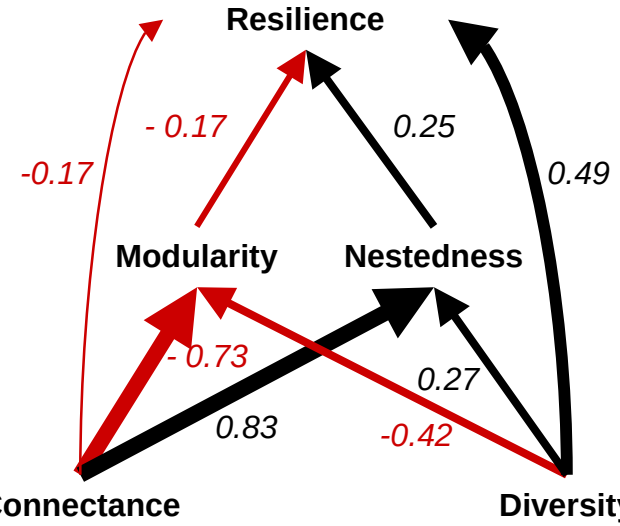
Results: impact of network structure on resilience



Mutualistic

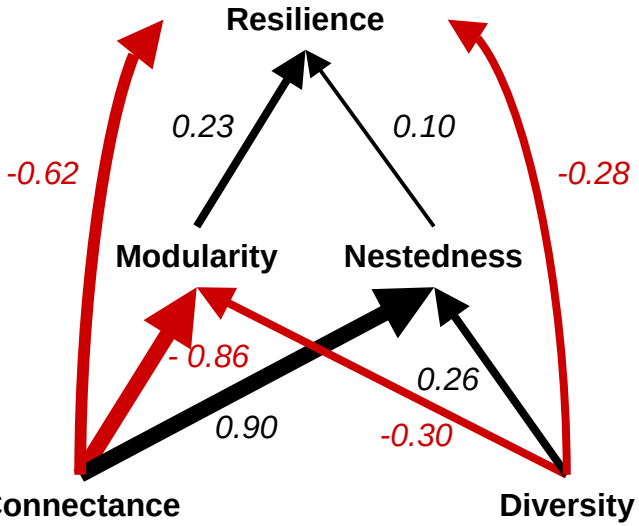


Trophic



indirect effect: 0. 32

indirect effect: 0.13

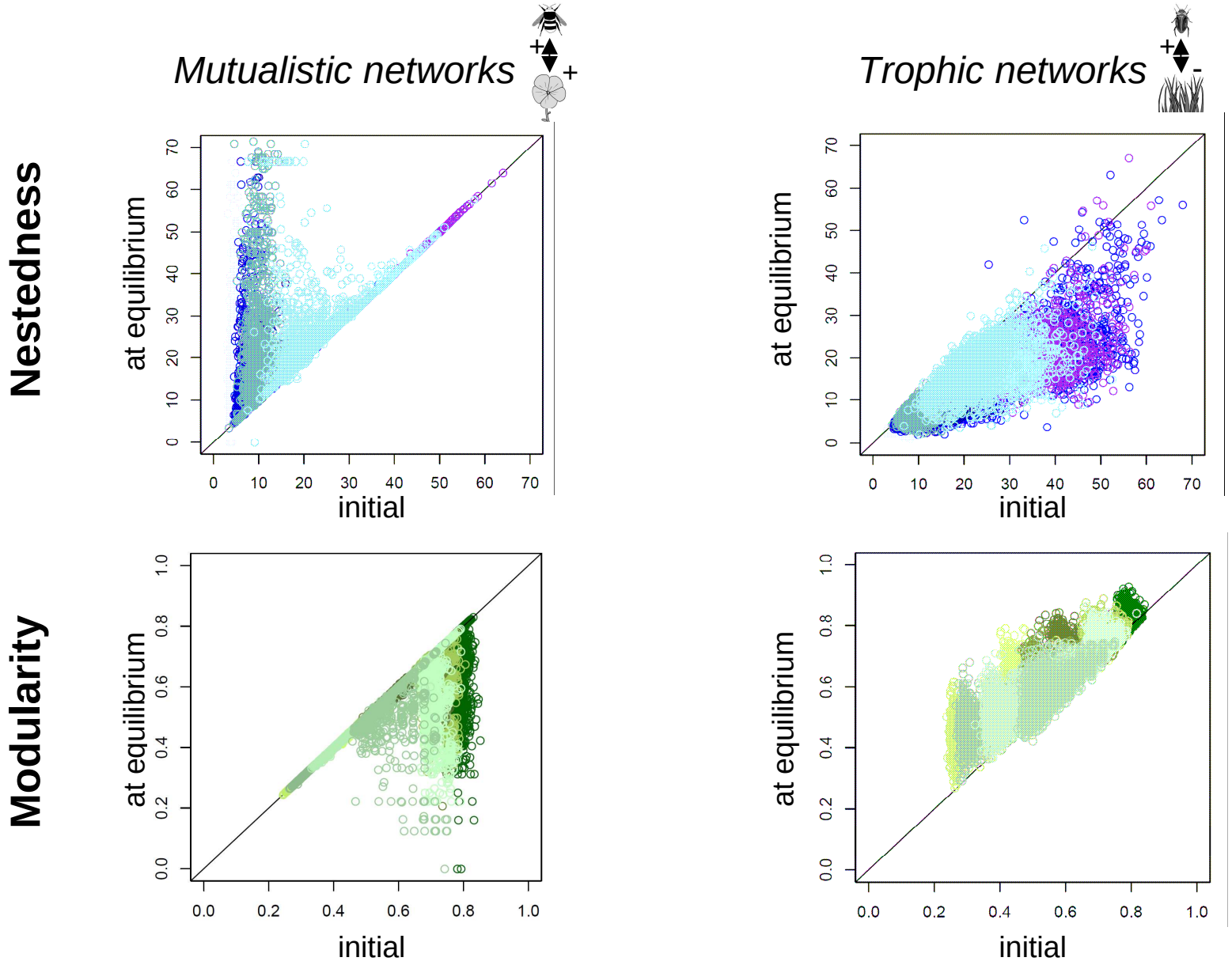


indirect effect: -0.10

indirect effect: -0.04

➢ opposite effect of network structure on the resilience of mutualistic and trophic networks

Results: network structure at equilibrium



Conclusions and Perspectives

Mutualistic networks 

Trophic networks 

Strong effects of network structure on community stability that differ between interaction types

- Connectance and diversity promote stability
- Modularity has a destabilizing effect
- Connectance and diversity have destabilizing effects
- Nestedness has a destabilizing effect

Importance of the fine architecture of interaction networks in determining their stability

Conclusions and Perspectives

Mutualistic networks 

Trophic networks 

Strong effects of network structure on community stability that differ between interaction types

- Connectance and diversity promote stability
- Modularity has a destabilizing effect
- Connectance and diversity have destabilizing effects
- Nestedness has a destabilizing effect

Importance of the fine architecture of interaction networks in determining their stability

Although different, the architectures of mutualistic and trophic networks both promote stability

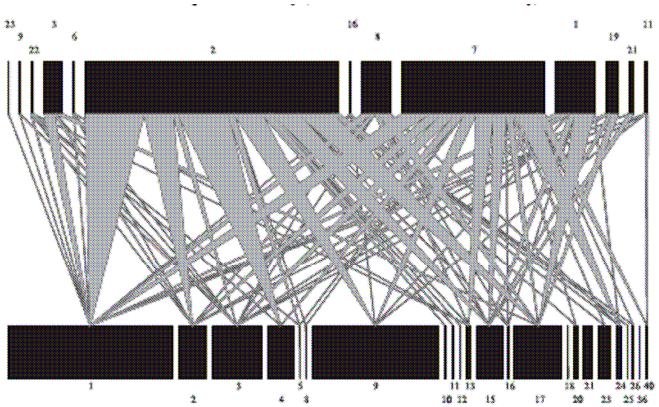
Conclusions and Perspectives

- Comparison between networks of different interaction types offers promising approaches to understand the response of communities to disturbances

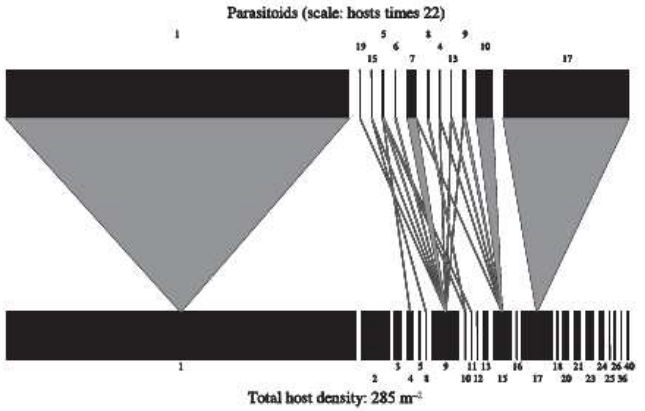
Conclusions and Perspectives

➢ Comparison between networks of different interaction types offers promising approaches to understand the response of communities to disturbances

Impact of interaction intimacy?



Van Veen et al. 2008



interactions during a short time scale

interaction intimacy

interaction during all or part of the life with the same individual

predator-prey
pollination

host-parasite
mycorrhizae

Conclusions and Perspectives

➢ Comparison between networks of different interaction types offers promising approaches to understand the response of communities to disturbances

Impact of interaction intimacy?

effects of network structure on community stability that depend on interaction intimacy?

Conclusions and Perspectives

➢ Comparison between networks of different interaction types offers promising approaches to understand the response of communities to disturbances

Impact of interaction intimacy?

effects of network structure on community stability that depend on interaction intimacy?

		Effect of species j on i (i.e., sign of a_{ij})		
		+	0	−
Effect of species i on j (i.e., sign of a_{ji})	+	++	+0	+−
	0	0+	00	0−
	−	−+	−0	−−

Apart from complete independence, there are five distinguishably different categories of interaction between any given pair of species, namely commensalism (+0), amensalism (−0) mutualism or symbiosis (++), competition (−−), and general predator-prey (+−) including plant-herbivore, parasite-host, and so on.

May 1973

Conclusions and Perspectives

➢ Comparison between networks of different interaction types offers promising approaches to understand the response of communities to disturbances

Impact of interaction intimacy?

effects of network structure on community stability that depend on interaction intimacy?

Model different life stages:

- free-living stage

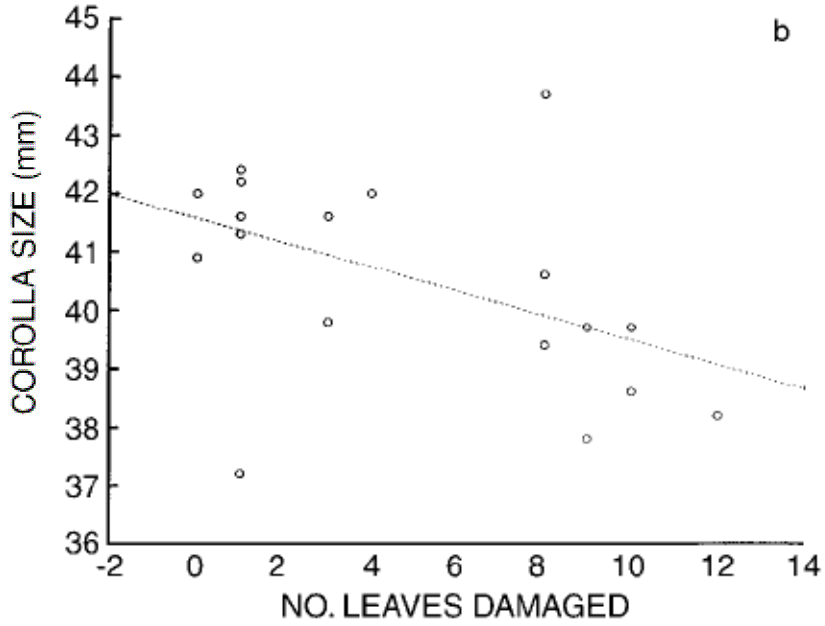
- parasite within hosts

Anderson and May 1978

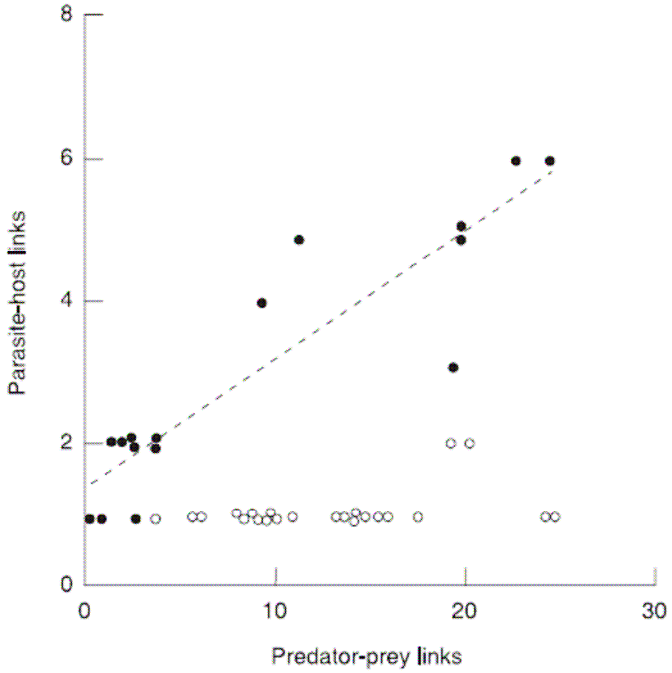
Conclusions and Perspectives

- Comparison between networks of different interaction types offers promising approaches to understand the response of communities to disturbances

- Consequences of combining different types of interactions in ecological networks



Strauss 1997



Amundsen et al. 2009

Conclusions and Perspectives

- Comparison between networks of different interaction types offers promising approaches to understand the response of communities to disturbances

- Consequences of combining different types of interactions in ecological networks

- Importance of evolutionary processes

Different coevolutionary mechanisms?

(Thompson 2005, Bascompte et al. 2006)

Mutualistic networks 

- complementarity and convergence of traits in interacting species.

- importance of flower morphology on the structure of plant-pollinator networks

Trophic networks 

- coevolution of defences and counter defences between interacting species.

- importance of chemical compounds on plant – insect herbivores interaction

Acknowledgements

Most of the pollination networks were provided by the Interaction Web Database (http://www.nceas.ucsb.edu/interactionweb/index.html)

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Mutualistic interactions

Trophic interactions

Thank you for your attention